THE EFFECTS OF SODIUM DIACETATE AND/OR SODIUM LACTATE ON THE STORAGE STABILITY OF A RESTRUCTURED TURKEY STEAK MANUFACTURED WITH FIBRINOGEN-THROMBIN BINDING SYSTEM

By

MOHAMED SHAFIT HUSSAIN

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I dedicate this dissertation to my wife, Azlin Idris, and to my children, Muhammad Adri, Atika Illyani, Aida Shafinaz, and Muhammad Adib. Without their support and understanding, I certainly never would have accomplished this work.

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TABLE OF CONTENTS

ACKNOWLEDGMENTS iii

LIST OF TABLES vi

LIST OF FIGURES xii

ABSTRACT xiv

INTRODUCTION 1

REVIEW OF LITERATURE 4

- Restructured Meat 4
- Cold-set Binders 7
- Preservatives of Interest 9
  - Sodium Diacetate 11
  - Sodium Lactate 15
  - Sodium Lactate as Flavor Enhancer and Antioxidant 15
  - Sodium Lactate as Antimicrobial Agent 21
- Mechanism of Action of Organic Acids 27
- Meat Color 34

MATERIALS AND METHODS 41

- Materials 41
- Preparation of Fibrimex® 42
- Processing of Restructured Turkey Breast 42
- pH Measurement 47
- Color Measurement 47
- Yield Parameters 48
- Sensory Analyses 48
- Binding Measurements 50
- Microbiological Examination 51
- Chemical Analyses 52

Statistical Analyses 54

RESULTS AND DISCUSSION 55

Microbiological Study 55
Psychrotrophic Counts 55
pH of Steaks from Microbiological Analyses . . 62
Meat Quality 69
Water Activity 69
Surface pH 75
Binding Integrity Score 82
Binding Score 85
Binding Strength 91
Objective Color Measurement for L* Value . . . 97
Objective Color Measurement for a* Value . . 109
Objective Color Measurement for b* Value . . 118
Thaw Loss 128
Cooking Yield 132
2-Thiobarbituric Acid Test 136
Proximate Composition 138
Sensory Evaluations 142

SUMMARY AND CONCLUSION 152

REFERENCES 158

BIOGRAPHICAL SKETCH 172

LIST OF TABLES

Table page

1. Formulations for restructured turkey steaks from restructured turkey breasts made with Fibrimex® and treated with sodium lactate and/or sodium diacetate 43

2. Mean for total psychrotrophic counts of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).. 59

3. Mean for pH of sample homogenate of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD). 66

4. Mean for surface pH from microbiological analyses of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 68

5. Slope values for water activity (Aw) of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex®, and treated with sodium lactate and/or sodium diacetate 72

6. Least square mean values of water activity (Aw) for restructured turkey steaks made

with Fibrimex® and treated with sodium lactate and/or sodium diacetate 73

7. P-values of comparisons for water activity (Aw) of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 74

8. Slope values for surface pH of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) mad with Fibrimex® and treated with sodium lactate and/or sodium diacetate 78

9. Least square mean values of surface pH for restructured turkey steaks made with Fibrimex® and treated sodium lactate and/or sodium diacetate 79

10. P-values of comparisons for surface pH of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 81

11. Slope values for binding integrity scores of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 84

12. Least square mean values of binding integrity scores for restructured turkey steaks made with Fibrimex® and treated sodium lactate (NaL) and/or sodium diacetate (NaD) 86

13. P-values of comparisons for binding integrity scores of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 87

14. Slope values for binding scores of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with

Fibrimex® and treated sodium lactate and/or sodium diacetate 90

15. Least square mean values of binding scores for restructured turkey steak made with Fibrimex® and treated with sodium lactate and/or sodium diacetate 92

16. P-values of comparisons for binding scores of steaks made with Fibrimex® and treated sodium lactate (NaL) and/or sodium diacetate (NaD) 93

17. Least square mean values of binding strength (kgf) of the restructured turkey steak made with Fibrimex® and treated sodium lactate and/or sodium diacetate 94

18. P-values of comparisons for the binding strength (kgf) of restructured turkey steaks made with Fibrimex® and treated sodium lactate and/or sodium diacetate 96

19. Slope of L* values for steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate 100

20. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 101

21. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 102

22. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 103

23. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 104

24. Slope of a* values for turkey steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate . . . 111

25. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 113

26. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 114

27. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 115

28. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 116

29. Slope of b* values for turkey steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate . . . 120

30. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made

with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 122

31. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 123

32. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 124

33. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 125

34. Mean for thaw loss of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 131

35. Mean for cooking yield of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 134

36. Least square mean for 2-Thiobarbituric Acid values[a] (mg malonaldehyde/kg) of steaks made with Fibrimex®, and treated with sodium lactate and/or sodium diacetate 137

37. P-values of comparisons for 2-Thiobarbituric Acid values of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 139

38. Mean proximate composition for steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 140

39. Mean values for flavor intensity scores of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 143

40. Mean values for juiceness scores of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) 145

41. Mean values for off-flavor scores of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 1 147

42. Mean values for off-flavor scores of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 2 148

43. Mean values for off-flavor scores of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 3 149

LIST OF FIGURES

Figure page

1. Processing of restructured turkey steaks with sodium diacetate (NaD) and/or sodium lactate (NaL) . 44

2. Psychrotrophic counts of steaks sliced from restructured turkey breast made with Fibrimex, treated with sodium lactate (NaL)and/or sodium diacetate (NaD), and stored for 10 days at 0°C . . . 57

3. Mean pH values from sample homogenate of steaks treated with sodium lactate (NaL) and/or sodium diactate (NaD), and stored at 0°C for 10 days . . . 63

4. Mean surface pH values for the microbiological samples of the restructured turkey steaks manufactured with Fibrimex, treated with sodium lactate (NaL) and/or sodium diactate (NaD), and stored at 0°C for 10 days 64

5. Mean water activity values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C . . . 70

6. Mean surface pH values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C 76

7. Mean binding integrity scores for steaks stored for 8 days at 0°C that were sliced from restructured turkey breasts made with Fibrimex, treated with sodium lactate (NaL) and/or sodium diacetate (NaD), and stored for at

different storage times (0, 1, 2, and 3 months) at -30°C 83

8. Mean binding scores for steaks stored for 8 days at 0°C that were sliced from restructured turkey breasts made with Fibrimex, treated with sodium lactate (NaL) and/or sodium diacetate (NaD), and stored for at different storage times (0, 1, 2, and 3 months) at -30°C 88

9. Mean L* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 month at -30°C 98

10. Mean a* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C 110

11. Mean b* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C 119

12. Mean of purge values for restructured turkey meat made with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD), stored at -30°C for a period of 0, 1, 2, and 3 months 129

13. Mean cooking yield values for restructured turkey meat made with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD), stored at -30°C for a period of 0, 1, 2, and 3 months . . 133

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THE EFFECTS OF SODIUM DIACETATE AND/OR SODIUM LACTATE ON THE STORAGE STABILITY OF A RESTRUCTURED TURKEY STEAK MANUFACTURED WITH FIBRINOGEN-THROMBIN BINDING SYSTEM

By

MOHAMED SHAFIT HUSSAIN

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Chairperson: Dr. Sally K. Williams
Major Department: Animal Science

The objectives of this research were 1) to determine the effect of sodium diacetate (NaD) and/or sodium lactate (NaL) on the total psychrotrophic microflora, and 2) to ascertain the effects of sodium diacetate and/or sodium lactate treatments on sensory, chemical and physical characteristics of the restructured turkey steaks processed with the Fibrimex® binding system. The restructured turkey breasts were treated with either 1.5% NaL, 2.0% NaL, 1.5% NaL + 0.1% NaD, 2.0% NaL + 0.1% NaD, 0.1% NaD, or control. All sample treatments were stored at -30°C for 0, 1, 2, and 3 months. At each storage period, the restructured turkey breasts were sliced into 1 cm thick steaks, and evaluated for psychrotrophic counts, water activity, surface pH, binding integrity score, binding score, juiciness, flavor intensity, off-flavor, binding strength, proximate composition, and 2-thiobarbituric acid test (TBA).

Sodium diacetate when used alone at 0.1% level or when used in combination with either 1.5% or 2.0% NaL significantly ($P<0.05$) reduced the growth of psychrotrophic microflora, and extended the shelf life of the restructured turkey steaks when compared with control and steaks treated with 1.5% or 2.0% NaL. Sodium lactate and NaD when used together resulted in a synergistic effect.

Even though steaks treated with NaD and/or NaL had lower binding strength ($P<0.05$), the Fibrimex® binding system was able to hold the meat pieces together without falling apart when handled. There were no significant differences ($P>0.05$) for cooking yield, fat, moisture, protein, and juiciness among the treatments. Ash content was higher for steaks with NaL ($P<0.05$). At months 1, 2, and 3, steaks formulated with either NaL or combined with NaD had lower thaw loss than control or steaks formulated with NaD ($P<0.05$). The TBA values for all steaks formulated with NaD and/or NaL were higher than control ($P<0.05$). In conclusion, NaD and/or NaL can be used with Fibrimex® in restructured turkey steaks.

INTRODUCTION

With consumer demand for convenience and variety meat products unlikely to change, interest in restructured products is expected to continue. With today's life style, there appear to be substantial opportunities in the commercial processing, hotel-restaurant-institutional (HRI), retail and fast food areas for restructured meat products. Producing new meat products that meet the needs of cafeterias, fast food outlets, airliners, hospitals, and restaurants can be accomplished through restructuring technology, especially with the presence of binders such as Fibrimex®.

The conventional method for production of restructured meat products requires more time because of an additional step called tumbling. With this study, a new method of manufacturing restructured turkey breast is developed without the need of tumbling the meat. Fibrimex® is a blood-based binding system. The mechanism is based on the blood clotting action between fibrinogen and thrombin. Since Fibrimex® is a protein, it is a good source for bacterial multiplication; thus means of preventing, eliminating, or reducting of bacterial multiplication is crucial. The product shelf life could be extended by incorporating sodium lactate and/or sodium diacetate in a restructured turkey breast with Fibrimex®. By shortening the process time without undergoing tumbling to achieve adhesion, and by extending the shelf life of the product, the meat and poultry industries may enjoy economic gains. In addition, they could also increase marketing alternatives for other meat and poultry cuts by utilizing the same principle employed in this study.

Currently, Fibrimex® is added to the meat as is. There is no publication on immobilization of sodium diacetate and sodium lactate in Fibrimex®. All previous studies conducted using sodium diacetate were done on laboratory scale using liquid media or slurries, not on actual food product formulations. There are potential pitfalls in translating results from studies in liquid media to actual food products (Blom et al., 1997). Many of meat characteristics such as drip, color, and tenderness are affected by freezing (Hamm, 1986) and the addition of preservatives (Maca et al., 1999; Shelef and Potluri, 1995; Kotula and Thelappurate, 1994; Papadopoulos et al., 1991c). Upon thawing, the amount of exudate from the meat is related to the pH of the meat before freezing (Hamm, 1986; Hamm, 1960). If there is too much exudate, then the meat will appear as unattractive to the consumer. Besides, the exudate may interfere with the binding strength of

Fibrimex®. Papadopoulos et al. (1991c) documented that sodium lactate increased muscle tenderness and decreased shear force, but the the mechanism is not understood. These changes could interfere with the binding strength of Fibrimex®. Therefore, the objectives of this research were 1) to determine the effect of sodium diacetate and/or sodium lactate on the total psychrotrophic microflora and 2) to ascertain the effects of sodium diacetate and/or sodium lactate treatments on sensory, chemical, and physical characteristics of the restructured turkey steaks processed with the Fibrimex® binding system. If successful, this project could have a positive impact on the poultry and meat industry where new products utilizing Fibrimex® could be marketed with extended shelf life.

REVIEW OF LITERATURE

Restructured Meat

There is always an interest in utilizing low value meat to produce higher value products. Such approach is the basis for restructured meat research work. Restructured or engineered meat is defined as the reassembling of pieces or particles of meat in such a way that the end product has pleasing flavor, textural, and masticatory properties. Restructuring is an evolving technology which facilitates the production of new meat products of enhanced value from cuts of lesser value, or from value cuts that could increase further the choice for consumers to purchase new meat products.

Restructuring offers the opportunity to produce a product with both weight and shape control. Products can be formulated to specified compositional standards. Fat content can be carefully controlled. Mouthfeel, juiciness and binding of the product can also be controlled. Restructuring makes possible effective utilization of trimmings and low-value primal cuts which are good sources of protein, but which are often underutilized.

Therefore, with restructuring technology, it is possible to provide the consumer with a highly palatable product at a reasonable cost.

Large quantities of a wide variety of restructured meat products are sold in the USA, the UK and Europe. The most rapidly expanding restructured meat products market areas in the USA are fast foods and convenience products. Fast food applications have been very successful for restructured meat products in the USA. McDonald's Pork McRib Sandwich being a successful example (Smith, 1984). Restructured products have become an important and established sector of the UK market (Jolley *et al.*, 1987). The increase in sales of restructured meats in the UK retail market has been a success story.

The poultry industry has pointed the way and has ventured successfully into restructuring of meat. The poultry industry offers an increasing variety of products suitable for the hotel-restaurant-institutional (HRI), fast food and convenience food markets. There is a wide range of so-called 'finger foods', including nuggets, drumsticks and chicken patties. These products may be frozen, breaded or battered, precooked and suitable for various reheating methods. Similarly, the red meat industry already produces a wide range of products intended for the HRI and fast foods market such as breaded schnitzel, breaded cutlets, breaded chops, breaded sausages, toastburgers and assorted meat patties. A wide variety of cured and smoked products have also been developed.

In Australia, the range of chicken products has recently been further extended by products closely resembling some of the traditional bone-in cuts such as drumsticks and wings, but without the bones (Smith, 1989). These are made possible by restructuring and forming technology. It is claimed that 70-75% of all diced meat being canned in the USA, such as stews, is restructured (Smith, 1984). Such diced meat is also very suitable for meat pies as well as other applications.

In restructured meat research, work is aimed at finding methods of increasing meat binding properties so that the texture of restructured meat products better simulates that of intact muscle meat. Previously, restructured meat products were made with binders where heat was required. These products, however must be either frozen, cooked while in frozen state, or sold as already cooked products. Given the choice, consumers preferred chilled meats over frozen meats since they associate freshness with chilled meats. Therefore, researchers are continuously searching for binders not requiring heat. Such binders that could bind meat without requiring heat are called cold-set binders, and could bind meat pieces at cold storage conditions.

Cold-set Binders

Many binders have been tested for their suitability as cold-set binders for production of restructured products. One such binder that has been greatly researched is alginate. The alginate gel binds the product together in both the raw and cooked state. It was reported that the binding strength of alginate and surface discoloration of the meat were not affected by refrigerated storage of meat blocks up to 35 days (Muller et al., 1991). Thus, the advantage of a cold-set binder is that the products can be distributed either fresh or frozen, and if frozen can be thawed and displayed on retail cooler if required. Alginate is a hydrocolloid which reacts at cold temperatures to form a stable gel. The addition of calcium carbonate (0.13%) with sodium alginate (0.7%) resulted in minimum discoloration and maximum raw and cooked bind-strength (Trout, 1989).

The process of binding meat with the algin/calcium gelation mechanism was awarded a patent, and it was approved for commercial use by the United State Department of Agriculture (Muller et al, 1991). Thus, the algin/calcium gel mechanism can be used to produce structured beef steaks which bind, not only in the cooked state, but also in the raw, refrigerated state. This mechanism allows structured meat products to be marketed at the retail meat case with fresh meats. Production of restructured beef steaks using the algin/calcium gel mechanism does not require addition of salt or phosphates for effective binding. Detrimental oxidative effects of salt on restructured products can, therefore, be avoided. Sodium hypertensive individuals may benefit from production of structured meat products low in sodium content.

Fibrimex® is another cold-set binder that could be used in restructured meat products. The product is patented and developed by TNO Nutrition in Netherlands. It also does not depend on tumbling and cooking to accomplish binding. There is no need to add sodium or phosphates to achieve adhesion. Fibrimex® is a 100% natural product composed of fibrinogen and thrombin, and is approved by the Agriculture Canada, Health Protection Canada, USDA and FDA (FNA Foods Inc., 1996). With Fibrimex® there is no need to freeze the product. Good binding characteristics were achieved with whole tenderloins stuffed in a tubular casing, stored for 6 to 8 hours in a cooler that yielded 99% center cut steaks (FNA Foods Inc., 1996). Fibrimex® could bind whole muscles or pieces of fresh meat, poultry, fish, seafood , or any combination of the four into one. The binding is due to the formation of fibrin network. The fibrin monomers are derived from a precursor, fibrinogen, by proteolytic cleavages that release small fibrinopeptides, thus fibrin molecules are able to stick together (Mathews and van Holde, 1990). The removal of these small polar peptides during the formation of a fibrin clot (fibrinopeptides A and B) from the amino termini of the alpha and beta chains of fibrinogen by thrombin, resulted in polymerization of the resultant fibrin monomers to form a noncovalently bound gel, and covalent cross-linking in the presence of activated factor XIII (Fibrin Stabilizing Factor) and calcium ion (Laudano and Doolittle, 1981). The proteolysis of fibrinogen to fibrin is catalyzed by the serine protease thrombin which is produced from prothrombin. Thrombin has sequence and structural similarities to trypsin, but with a very specific function whereby it cleaves only a few types of bonds, mainly arginine-glycine (Mathews and van Holde, 1990).

Preservatives of Interest

There is renewed interest in the use of preservatives embedded into a gel matrix, and then coated onto a meat surface. Some researchers have found that such practice improved the efficiency of the preservatives against microorganisms. Cutter and Siragusa (1996) found that nisin when immobilized in calcium alginate gel suppressed *Brochothrix thermosphacta* growth, while nisin treatment alone did not suppress the growth of the bacteria inoculated on the lean and adipose tissues of beef surfaces. This study demonstrates that immobilization of nisin in a gel may be a more effective delivery system of a bacteriocin to the carcass surface than direct application. Similarly, lactic acid (1.7% v/v) when immobilized in the gel, reduced *Listeria monocytogenes* growth by 1.8 $\log_{10}$ counts versus 0.96 for acid treatment alone (Siragusa and Dickson, 1993; Siragusa and Dickson, 1992). The authors also observed a similar trend for *Salmonella typhimurium* and *Escherichia coli* 0157:H7. They also found that acetic acid (2% v/v) immobilized in the gel reduced *L. monocytogenes* counts 1.5 versus 0.25 log units when the acid was applied alone on the beef tissues. However, Yen et al. (1992) observed that algin with calcium meat binder when incorporated with 3.0% sodium lactate did not affect the extent of destruction of *L. monocytogenes* in ground pork by heat. This method of applying organic acids with alginate gel has been documented in the Code of Federal Regulations (CFR, 1997a). In this regulation, the sodium lactate, calcium carbonate, lactic acid/calcium lactate/glucono delta-lactone must not exceed 1%, 0.2%, and 0.3% respectively in the product formulation. The added mixture may not exceed 1.5% of product formulation, and the ingredients of the mixture must be added dry.

There is a limited number of publications on the immobilization of acids or preservatives in a gel matrix for meat and meat products. However, much work had been done pertaining to the use of organic acids as dips and additives in food formulations for their antibacterial properties, to extend the shelf life of meat and meat products. Acids such as lactic, acetic, benzoic, sorbate and their salts have been tested individually or in various combinations to see any synergistic effects against bacteria. Sodium diacetate has not been given much emphasis in relation to meat and meat products. As for sodium lactate, since late 1980's, several papers have been published that documented the potential use of this compound in meat product formulations. In order for a preservative to be useful to the meat processors, it must not cause deleterious effects on meat color, odor or flavor, but yet have good bacteriostatic properties.

Sodium diacetate

Sodium diacetate ($CH_3COOH.CH_3COONa$) is a white powder of acetic acid (about 40%) and sodium acetate. The compound is generally recognized as safe (GRAS) under the United States Food Regulations. It is used in foods for flavoring, adjuvant, pH control, and antimicrobial (CFR, 1997b). The acceptable daily intake as documented by the Food and Agriculture Organization (FAO) for humans for sodium diacetate is 0-15 mg/kg body weight (FAO, 1973).

This compound may be used in cheese spread, malt syrups, butter, and wrapping material (Branen and Davidson, 1983). In bread and cake products, sodium diacetate can be used from 0.25-0.4% levels (Glabe and Maryanski, 1981). It is very effective in the baking industry against bread mold and rope-forming bacteria, such as *Bacillus mesentericus* (*subtilis*), while having little effect on baker's yeast (Glabe and Maryanski, 1981). Levels of 0.10-0.12% were found to be effective against *Bacillus* spp. (Glabe and Maryanski, 1981). The authors also documented that at levels not exceeding 0.5%, sodium diacetate inhibited mold growth and sporulation. At 0.1-0.5% it inhibited *Aspergillus flavus*, *A. fumigatus*, *A. niger*, *A. glaucus*, *Penicillium expansum*, and *Mucor pusillus* when tested in potato dextrose agar, feeds and silage (Glabe and Maryanski, 1981). Application of 0.5% sodium diacetate on butter wrappers prevented mold growth (Chichester and Tanner, 1972).

Before 1993, there were no available documents on the use of sodium diacetate as a food preservative against foodborne bacteria in meats in the United States. In a laboratory scale study utilizing vacuum packaged ready-to-eat turkey breast meat slurry

(25% meat in water), Schlyter *et al.* (1993b) reported that antilisterial activity was enhanced in treatments containing lactate with 0.3% diacetate at 25°C and lactate with 0.1% diacetate at 4°C, compared to similar treatments containing diacetate or lactate alone. The pH of the slurries containing 0.3 or 0.5% diacetate was 5.5 and 5.2, respectively, but lactate (pH 6.3) in the slurries had a negligible effect on pH compared to the control (pH 6.2). The authors indicated that the increased antilisterial activity in slurries with diacetate in combination with other additives was due to synergistic effects and not just pH (Schlyter *et al.*, 1993b). In another study using turkey breast meat slurry, Schlyter *et al.* (1993a) demonstrated that the addition of the compound at 0.3% level extended the generation time (7 hour) compared to the control (1.7 hour).

Shelef and Addala (1994) also conducted a laboratory scale research to study the potency of this compound as a food preservative in meat. They found that the addition of sodium diacetate to beef roast slurry suppressed total aerobic counts during refrigerated storage. Even though the pH was lowered from 5.6 to 5.2 by the addition of sodium diacetate, a major part of the antimicrobial effect was attributed to the diacetate and not just pH (Shelef and Addala, 1994). Growth of *L. monocytogenes*, *E. coli*, *Pseudomonas fluorescens*, *Salmonella enteriditis*, and

Shewanella putrefaciens were suppressed, but *P. fragi*, *Yersinia enterocolitica*, *Enterococcus faecalis*, *Lactobacillus fermentis*, and *Staphyloccus aureus* were insensitive to sodium diacetate (Shelef and Addala, 1994).

The use of sodium diacetate as a washing medium for blue crab meat was investigated by Degnan *et al.* (1994). They found that sodium diacetate (0.5 or 1M) resulted in a modest reduction of *L. monocytogenes* by day 2, but the organism was able to recover to its original level by day 6. Nevertheless, a greater reduction (2.6 $\log_{10}$ units/g within 6 days) was achieved when the crab meat was washed with 2M sodium diacetate solution. In Australia, a new technology for Salmonella control and shelf life extension was documented by Moye and Chambers (1991). By surface application of sodium diacetate powder (1-3 mg/cm^2 or 2-6 gm per chicken), the shelf life of the whole chicken was extended by approximately 4 days at 2°C, however, a 10 days shelf life extension was achieved for chicken pieces with significant Salmonella reduction (Moye and Chambers, 1991). Their findings were commercially tested in a factory trial at a line speed of up to 140 carcasses a minute, and the technology was found to be commercially viable.

Sodium lactate

Sodium lactate ($CH_3CHOHCOONa$) is generally available as 60% aqueous solution with a neutral pH (Shelef, 1994). It is a very hygroscopic salt with a mild saline taste and has strong humectant properties (Houtsma, 1996). The U.S. Food and Drug Administration (FDA) regarded it as a GRAS (generally recognized as save) substance for use in foods as a direct food ingredient (CFR, 1993). The salt is also approved by the USDA as a flavoring agent in meat and poultry products at a level of 2% based on the actual sodium lactate (which is 3.33% of the 60% commercially available solution) (Shelef and Yang, 1991).

Sodium Lactate as Flavor Enhancer and Antioxidant

Sodium lactate is currently being used in the meat industry for flavor enhancement and shelf life extension (PURAC, 1997a; Duxbury, 1988). In all products covered by regulation 9 CFR 319.180 (emulsified products such as frankfurters, bologna, wieners, etc.), lactate is permitted at up to 2% of the total formulation (3.3% of the 60% solution) may be used in all meat products where flavors are allowed (PURAC, 1997b). However, lactates up to 4.8% of the total formulation (8.0% of the 60% solution) are permitted for hermetically sealed meat products that is not covered under 9 CFR 319.180 (PURAC, 1997b).

Flavor notes associated with beef were enhanced by addition of sodium lactate, and flavor deterioration associated with warmed-over flavor development and microbial growth during storage were minimized (Maca et al., 1997b; Papadopoulos et al., 1991a; Papadopoulos et al., 1991c). Palatability attributes such as juiciness and tenderness were improved by addition of 1% sodium lactate, but increasing it did not further affect palatability (Papadopoulos et al., 1991c). Maca et al. (1997b) observed that cooked, vacuum-packaged beef top rounds containing 3% or 4% sodium lactate were not juicier that the control roasts. However, with ground pork, O'Connor et al. (1993) found that addition of 1.5% or 3.0% sodium lactate was juicier than ground pork without sodium lactate. Nevertheless, they reported that the lower level of sodium lactate was juicier. Juiciness decreased significantly during storage of cooked, vacuum packaged roast beef that did not contain sodium lactate (Papadopoulos et al., 1991c). However, incorporation of 1 to 4% sodium lactate improved juiciness at 0 day of storage, and stabilized juiciness throughout storage. Papadopoulos et al. (1991c) also found that the fat and moisture contents of the products did not differ between sodium lactate levels, indicating neither water nor fat was bound preferentially by sodium lactate. Bradford et al. (1993) indicated that lactate is not fat soluble.

Panelists described beef roasts with sodium lactate as flavorful with stronger beefy flavor than the untreated samples (Maca et al., 1997b; Papadopoulos et al., 1991a). However, panelists felt mild throat irritation in the roasts treated with 4% sodium lactate (Papadopoulos et al., 1991c). Lactic acid concentration increased with increasing level of sodium lactate.

Addition of 2% and 3% sodium lactate to fresh pork sausage delayed microbial deterioration, pH decline, and development of sour and off-flavors at 4°C (Brewer et al., 1991). Sodium lactate also enhanced the salty-flavors in the sausage (Brewer et al., 1991). Salty flavor intensity increased up to day 17 then decreased to day 21. Brewer et al. (1991) suggested that the salty flavor may have been overpowered by sour and off-flavor between day 17 and 21 due to microbial growth. Papadopoulos et al. (1991c) also noted that sour and salty tastes increased with increased sodium lactate. According to PURAC America, Inc., the distributor of sodium lactate in the U.S.A., sodium lactate contains 12% sodium.

Papadopoulos et al. (1991a, 1991c) revealed that warmed-over-flavor notes were minimized, while the positive fresh flavor notes were enhanced by sodium lactate. Maas et al. (1989) observed that at 2.5 % sodium lactate was organoleptically acceptable, however, at 3.5% level, off-flavors were detected by the panelists. Papadopoulos et al. (1991c) observed a significant increase in "off-notes" such as cardboard, painty and fishy aromatics for cooked, vacuum packaged beef top rounds injected with 0, 1, 2, 3, or 4% sodium lactate as the storage time increased. Such "off-notes" were associated with warmed-over-flavor (WOF) development in meats. Low cardboard flavor scores correspond with low 2-thiobarbituric acid (TBA) values (Maca et al., 1997b). However, the "off-notes" significantly decreased with increasing sodium lactate (Papadopoulos et al., 1991c). Maca et al. (1997b) reported that chemical flavors increased with increasing sodium lactate level. However, no chemical flavors were noted when sodium propionate at 0.1% or 0.2% level were combined with sodium lactate. They also noted that a higher metallic mouthfeel for roast beef containing 3.0% sodium lactate on day 0 than day 70. Brewer et al. (1991) observed that off-flavor scores were inversely related to sodium lactate level. After 21 days refrigerated storage, off-flavor intensity scores were not significantly different from day 0 for fresh pork sausage made with 2 or 3% sodium lactate (Brewer et al., 1991). They suggested that the inhibition of microbial growth delayed the onset of sour and off-flavors.

Brewer et al. (1991) observed that the TBA values of fresh pork sausage made with sodium lactate at 1, 2, or 3% level were unaffected. Similarly, Bradford et al. (1993) observed that 2% potassium lactate did not affect the TBARS (thiobarbituric acid reactive substances) values of the treated pork sausage stored for 12 day period. However, Nnanna et al. (1994) observed that sodium lactate at 20 g/kg suppressed oxidation in grounded pork meat stored up to 7 days of storage at 0 and 5°C, comparable with butylated hydroxytoluene (BHT) anhydrous (0.1 g/kg). However, at 14 days of storage, both control and treated samples had high TBARS (thiobarbituric acid reactive substances) values. Therefore, Nnanna et al. (1994) suggested that TBARS may not be a reliable index of oxidation after the 7th day of storage. The inhibition of peroxide value and conjugated diene formation by sodium lactate appeared to be concentration dependent. They also found that calcium lactate showed similar activity. Unda et al. (1991) observed that microwave-ready beef roast with 2.0% sodium lactate added had lower TBA values than roast without sodium lactate during week 0 of storage. However, no differences were found during week 5 of storage. Catfish fillets treated with 2% sodium lactate had a lower TBA values than untreated samples (Williams et al., 1995). Maca et al. (1997b) observed that when 0.1 or 0.2% sodium propionate with 3 or 4% sodium lactate were added to beef top rounds, cooked and then vacuum packaged, the TBA values were reduced to an unexpected level (0.03 to 0.04 mg malonaldehyde/kg sample) compared to the control (0.16 mg malonaldehyde/kg sample) and 3% sodium lactate (0.22 mg malonaldehyde/kg sample). Nnanna et al. (1994) proposed that the mechanism of sodium lactate antioxidant activity to be associated with Fe^{3+}-lactate complexation or lactyl radical reduction of Fe^{3+} to Fe^{2+} and subsequent chelation of Fe^{2+} by the carboxylate species. The chelation of Fe^{2+} is also important since Fe^{2+} is reactive and can catalyse lipid oxidation (Yamamoto et al., 1987). However, the exact mechanism by which sodium lactate may function as an antioxidant is still unknown (Nnanna et al., 1994). With respect to packaging methods, Kulshrestha and Rhee (1996) observed that lactate had a prooxidative effect in aerobically-packaged frozen beef patties but showed no such effect in vacuum-packaged frozen or refrigerated beef patties.

Besides enhancing flavor development, increasing the level sodium lactate resulted in higher cooking yield (Maca et al., 1997b; Kulshrestha and Rhee, 1996; Papadopoulos et al., 1991a; Papadopoulos et al., 1991c). Because of the hygroscopicity of sodium lactate, it enhanced the water holding capacity of the meat, thus controls purge and higher yield for cooked products (PURAC, 1997a). The increase in cooking yields with increasing sodium lactate could also be due to the increase in the levels of sodium ions, thus increased the water holding capacity of the meat.

Sodium lactate as Antimicrobial Agent

The potential benefits of sodium lactate as antimicrobial agent was realized in 1989 (Shelef, 1994). Since then, sodium lactate has been used successfully as an antimicrobial agent. Extended shelf life of meat products was achieved with sodium (Anonymous, 1988; Brewer et al., 1991; Lamkey et al., 1991; Papadopoulos et al., 1991a, 1991b, 1991c) and potassium lactate (Bradford et al., 1993). The sodium lactate increased the lag time and reduced the exponential growth of the microbes (Lamkey et al., 1991). Brewer et al. (1991) observed that fresh pork sausage with 0 and 1% sodium lactate had total plate count greater than 10^8 CFU/g by the 10th day of storage, while sausage with 2 and 3% sodium lactate had 10^8 CFU/g at 21st day of storage. Maas et al. (1989) demonstrated that sodium lactate at 2.0, 2.5, 3.0, or 3.5 % levels were effective in preventing growth of *C. botulinum* in comminuted raw turkey. The meat was cooked to an internal temperature of 71.1°C, vacuum packaged, and stored at 27°C for 10 days. Toxicity due to *C. botulinum* toxin occurred after 3, 4-5, 4-6, 7, or 7-8 days for each concentration, respectively. Therefore, the antibotulinal effect of sodium lactate was concentration dependent. Meng and Genigeorgis (1994) also observed that increasing levels of lactate and decreasing temperature significantly delayed toxigenesis of *Cl. botulinum* in the 'sous-vide' products. Maas et al. (1989) stated that the inhibitory component was the lactate moiety, not sodium ion. Toxin production was delayed by sodium lactate concentrations of 1.5 to 2.0% at 15°C and 20°C (Houtsma et al., 1994). With the incorporation of 2% or 3% sodium lactate in a peptone-yeast extract medium of pH 6.1 at 15°C, the growth and toxin production of *C. botulinum* were delayed for 14 and more than 49 days, respectively (Houtsma et al., 1994). Houtsma et al. (1994) also noted that 4% sodium lactate inhibited germination of the *C. botulinum* spores, which may explain the inhibitory effect of sodium lactate on growth and toxin production. Maas et al. (1989) suggested that a possible mechanism for the action of lactate was the inhibition of a major anaerobic energy metabolism pathway necessary for growth. The use of 1% and 7% lactates to delay the growth of *C. botulinum* in poultry and fish products that are uncured, cooked and packaged in a plastic barrier package is part of a patented technology (PURAC, 1997a) owned by PURAC America, Inc., U.S.A. (US patents no. 4,798,729; 4,888,191 and 5,017,391).

Unda *et al.* (1991) found that 2% sodium lactate inhibited *C. sporogenes* and *L. monocytogenes* in roasts that were temperature abused for 24 hr at 25°C which were then stored at 2-4°C for 2 weeks. Blom et al. (1997) observed that a mixture of 2.5% sodium lactate and 0.5% sodium acetate in ham and servelat meat products inhibited growth of *L. monocytogenes* during 5 weeks of storage at 4°C. Growth of *L. monocytogenes* at 4°C in Brain Heart Infusion broth of pH 5.5 was completely inhibited by the addition of 4.0% sodium lactate (Buncic et al., 1995). Shelef and Yang (1991) found that a 5.0% concentration of sodium or potassium lactate delayed the growth of *L. monocytogenes* in tryptic soy broth. Growth of *L. monocytogenes* decreased by using 4.0% lactate in comminuted chicken or beef when held at 35, 20, or 5°C. They concluded that the two salts gave comparable results and could be used interchangeably, again suggesting that the lactate moiety was the effective component.

Lactate influenced the growth of lactic acid bacteria in meat, depending upon the pH level and the atmospheric conditions under which postrigor meat was held (Grau, 1980). A 100 mM concentration of L-lactate buffered to pH 5.5 prevented the anaerobic growth of *Serratia liquefaciens, Y enterocolitica, Enterobacter cloacae, Aeromonas hydrophila* and aerobic growth of the aeromonad (Grau, 1981). At pH 6.1 the amount of L-lactate ordinarily found in muscle was not inhibitory to any of the strains. A concentration of 210 mM sodium L-lactate in a meat system permitted aerobic growth of *Brochothrix thermosphacta* down to pH 5.5, L-lactate inhibited anaerobic growth at the concentration found in postrigor meat (Grau, 1980).

Papadopoulos et al. (1991b) injected beef top rounds with 0-4% sodium lactate and then cooked and vacuum packaged the roasts. The aerobic plate counts for control meat increased to 7.5 log CFU/cm^2 after 84 days of storage, but the aerobic plate counts of the roasts with 4% sodium lactate increased to 6.4 log CFU/cm^2 in the same period. The microflora changed from predominantly staphylococci and micrococci at 0 days to coryneform, micrococci, lactobacilli, and yeasts at 42 days and to homo- and heterofermentative lactobacilli and streptococci at 84 days. Shelef and Yang (1991) suggested a possible water activity effect for sodium lactate, but Papadopoulos et al. (1991b) did not find this effect in their studies.

Lactates have been combined with other compounds in multiple-barrier studies. Lactic acid at 25-30 mEq in combination with sodium nitrite, potassium sorbate, or glycerol monolaurate enhanced inhibition of *S. aureus* grown anaerobically (Smith and Palumbo, 1980). Sodium lactate at the same concentration had no effect. Sodium lactate was less effective against microorganisms when sausage contained soy concentrate (Lamkey et al., 1991). Notermans and Dufrenne (1981) found that glyceryl monolaurate at a concentration of 5 g/kg of a meat slurry inhibited *C. botulinum* types A, B, and E only when lactic acid was used to reduce the pH to below 5.2. Rubin et al. (1982) observed a bactericidal effect against *Salmonella typhimurium* when the pH of the yogurt was lowered to 5.5 with lactic acid. Antibotulinal effects of salt and pH were observed for *C. botulinum* types A and B spores in sous vide spaghetti and meat sauce (Simpson et al., 1995).

Harmayani et al. (1991) looked at the interactive effects of sodium alginate and calcium or sodium lactate used in restructured meats on *Pseudomonas fragi* and *Salmonella typhimurium*. Inoculated ground beef was stored at 5°C for 5 days. Sodium alginate at concentrations of up to 0.8%, calcium lactate up to 0.3%, or a combination of the two did not affect growth of either organism. A 3 % concentration of sodium lactate only minimally affected the growth of *S. typhimurium* but did inhibit *P. fragi* at the 3 and 4% levels.

Fresh pork sausage formulated with 0-3 % sodium lactate was vacuum packaged and stored for up to 28 days at 4°C (Brewer et al., 1991). Using 10^8 CFU/g as a microbial end point, 1% sodium lactate delayed growth for 10 days, but a 2% level extended the time to 24 days. Using 4% potassium lactate and 3% sodium chloride reduced growth somewhat at 5°C. There did not appear to be a synergistic effect, between a 4% concentration of lactate combined with 140 ppm potassium nitrite. In an aerobically packaged ground pork without addition of salt, Brewer et al. (1995) found that aerobic plate count was best controlled by 3% sodium lactate.

Turner et al. (1996) studied the effect of sodium lactate on *Bacillus cereus* in sous vide chicken. Population of *B. cereus* was reduced by 0.5 to 1.0 log and by 3 logs in products heated to 77°C and 94°C, respectively. Turner et al. (1996) observed that *B. cereus* spores germinated within 1 day at 10°C, however, detectable changes in *B. cereus* populations were not evident through 28 days storage. One of the most significant finding related to sodium lactate as antibacterial agent was documented by Conner and Hall (1996). They observed that sodium lactate when applied on chicken meat at either 3% or 4% and stored at 4°C stimulated the growth of *E. coli* 0157:H7. Similarly, Kotrola and Conner (1997) observed that 4.0% sodium lactate enhanced survival of *E. coli* 0157:H7 in cooked turkey meat as compared to turkey meat without additives. However, Miller and Acuff (1994) observed that cooked, quartered beef top round roasts containing either 3.0 or 4.0% sodium lactate displayed limited proliferation of *E. coli* 0157:H7, *L. monocytogenes*, and *S. typhimurium* when compared with control roasts and roasts containing 2.0% sodium lactate.

Mechanism of Action of Organic Acids

Microbial growth in meat products is associated with meat quality reduction, spoilage, food safety, and economic loss. Salts of organic acids have been used to reduce the microbial growth on carcasses, meat, and meat products. Although organic acids are found to be effective in extending shelf life of meat products, and numerous theories have been suggested regarding the mechanism of inhibiting microbial growth, the exact mechanism of action has not yet been well defined (Houtsma, 1996; Shelef, 1994; Papadopoulos et al., 1991b).

Even though the specific action of lactate on the microbial cell is still unsolved, Shelef (1994) suggested some possible mechanisms such as lowering the intracellular pH of the microbial cell, interfering with cellular functions, reducing the water activity (Aw), and chelating iron. With respect to lowering the intracellular pH of the microbial cell, lipophilic organic acid molecules are able to diffuse freely across the cell membrane in the undissociated form. Lactic acid entered the cell in the undissociated state (Rubin et al., 1982). The undissociated form is the more effective inhibitor than the dissociated form (Salmond et al., 1984; Grau, 1980). Eklund (1983) stated that undissociated weak acids are 10 to 600 times as effective as the dissociated form.

The organic acids such as lactic acid exert an antimicrobial action which depends on 3 factors: (1) the effect solely of the pH, (2) the extent of dissociation of the acid, and (3) the specific effect related to the acid molecules such as (a) the potency to penetrate a cell, (b) the part of the cell which is attacked, and (c) the chemical nature of that attack (Smulders et al., 1986; Ingram et al., 1956). Gill and Newton (1982) pointed out that the pH fall is the most important of the three. By applying more acid or by lowering the pH, more undissociated molecules would be present (Ingram et al., 1956).

Undissociated acids penetrate the cell by means of diffusion and then dissociate to produce acidification of the cell interior (Rubin et al., 1982; Hunter and Segel, 1973). Uncharged molecules generally penetrate cells more readily than electrically charged ions (Hunter and Segel, 1973). The dissociated moiety once inside the cell cannot leave the cell in this form, thus it accumulates and lowers the internal pH of the cytoplasm of the cell. As the intracellular lactic acid concentration increased, generation time for *Salmonella typhimurium* growth also increased (Rubin et al., 1982). Rubin et al. (1982) found that the dissociated moiety of lactic acid was the predominant intracellular species at the end of bacteriostasis in the yogurt. They indicated that the dissociated intracellular lactic acid moiety was the species responsible for the bactericidal effect of *S. typhimurium* in the yogurt. This acidification occurs when the extracellular pH is lower than the intracellular pH, thus leading to the undissociated form to release its protons that acidify the cytoplasm (Shelef, 1994; Rubin et al., 1982). Therefore, acidification of the cytoplasm leads to structural changes in proteins, nucleic acids, and phospholipids, and collapse of the proton motive force, thus causing inhibition of nutrient transport that ultimately cause the cell to die (Shelef, 1994; Ronning and Frank, 1987 and 1988; Eklund, 1980; Freese et al., 1973; Hunter and Segel, 1973; Bosund, 1962). When the pH of the environment was lowered, Ruben et al. (1982) found that the intracellular concentration of lactic acid increased. Sanders and Slayman (1982) explained that at low external pH the passive influx of protons under the influence of the proton motive force could be a major problem for cells attempting to regulate their cytoplasmic pH. With acetic acid, denaturing of proteins inside the cell has been investigated as a mechanism of action (Reynolds, 1975), and lowering of internal pH by acetate in bacteria has been demonstrated by Huang et al. (1986).

However, the cell may also react by removing the excess protons from the cytoplasm to maintain a constant internal pH. By doing so, the cell has to spend more energy to maintain internal pH constant, thus reducing its ability to grow (Booth and Kroll, 1989; Kobayashi, 1985; Herrero, 1983). The mechanism of pH homeostasis in microorganisms is dependent upon expulsion of protons from the cytoplasm by proton ATPase (H^+-ATPase) at the expense of ATP (Kobayashi, 1985). If excessive accumulation of protons in the cytoplasm occur, then more ATP is required to expel the protons. Therefore, if the pH of the extracellular environment is lowered, the antimicrobial effectiveness of organic acids will increase. Williams (1993) demonstrated that lowering the pH of sodium lactate resulted in decreased microbial populations in treated catfish fillets. The microbial growth was retarded to the greatest degree when the pH was adjusted to pH 5.0 and below (Williams, 1993). An acid which decreases the pH of a food will extend the lag phase of the microorganisms (Williams, 1993; Greer, 1982).

With respect to a delay in the production of botulinal toxin (*Clostridium botulinum)* by lactate, Maas et al. (1989) suggested two possible mechanisms: first, by inhibiting anaerobic energy metabolism pathway that is essential for microbial growth; second, a high level of extracellular lactate may inhibit lactate efflux from the microbial cell coupled to ATP generation from proton transfer across cell membranes. Maas et al. (1989) also noted that the antimicrobial activity of lactate is greater at lower pH, principally due to the increase in undissociated form of the molecule.

There are indications that lactic acid acts on the microbial cell differently from other acids such as acetic and propionic (Moon, 1983). Inhibition of *Listeria monocytogenes* seems not to be associated with a decrease in intracellular pH (Young and Foegeding, 1993; Ita and Hutkins, 1991). For example, in response to extracellular lactic acid, *Listeria monocytogenes* was able to maintain its intracellular pH around 5.0 even when the external pH was reduced to 3.5 (Ita and Hutkins, 1991). *Listeria monocytogenes*, *L. innocua*, and *Lactococcus lactis* seem to be able to adapt to sodium lactate environment. Houtsma (1996) observed that *L. innocua*, and *Lactococcus lactis* which had been grown in the presence of sodium lactate were capable of regulating their intracellular pH due to increase in their proton ATPase activity. Therefore, other mechanisms could also be involved in the inhibition of microbial cell growth by lactate.

There is some evidence that bacterial inhibition by salts of lactic acid may be associated with effects on water activity (Aw) (Shelef, 1994; Houtsma et al., 1993; Chen and Shelef, 1992;

Anonymous, 1988). Maca et al. (1997b) observed that vacuum packaged cooked beef roast with 3% sodium lactate had lower Aw value than roast without sodium lactate. Also, addition of 1% sodium lactate to ham was found to reduce Aw, but it did not significantly affect pH, color or flavor of the product (Anonymous, 1988). The reduction of Aw with 1% sodium lactate or 1% sodium chloride added to the cooked ham was 0.005 and 0.01 units, respectively (Anonymous, 1988). It was shown that strains that were able to grow at Aw of 0.95 and below in the presence of sodium chloride (*Staphylococcus aureus*, *L. monocytogenes*, *Brochothrix thermospacta*) were inhibited by sodium lactate (Houtsma et al., 1993). However, 4% NaCl level alone did not inhibit *L. monocytogenes* growth whereas 4% sodium lactate did (Shelef, 1994). With the addition of 2% sodium lactate in a coarse liver pate', Debevere (1989) observed a decrease in the Aw from 0.960 to 0.945, and the product shelf life increased from 4 weeks to 6 weeks. Sodium lactate at 4% suppressed listerial growth, and depressed meat Aw (Chen and Shelef, 1992). Papadopoulos et al. (1991b) observed that Aw significantly decreased during storage of cooked, vacuum packaged beef top rounds injected with 0, 1, 2, 3, and 4% sodium lactate that were stored up to 84 days at 0°C. However, the Aw was not affected by level of sodium lactate. Mean values for the Aw ranged from 0.971

at 14 days storage to 0.948 at 84 days storage (Papadopoulos, 1991b). From this study, Papadopoulos et al.(1991b) stated that the reduction in Aw was not the main factor contributing to the bacteriostatic effect of sodium lactate. Shelef (1994) also stated that the effect of Aw by sodium lactate is small and insufficient to fully explain its antimicrobial effect. Chen and Shelef (1992) suggested that the depression of Aw alone cannot explain the inhibition of microbial growth by lactate because as with Chirife and Fontan (1980) work, Chen and Shelef (1992) also observed that sodium chloride (NaCl) was more effective than sodium lactate in lowering the Aw of the meat.

Another proposal by Shelef (1994) was that the ability of lactate to chelate iron. Hydroxycarboxylic acids (citric, lactic, malic and tartaric) have chelating properties (Shelef, 1994). Weaver and Shelef (1993) observed that pork liver sausage with lactate when cooked at high temperature (15 min at 121°C) resulted in the chelation of polyvalent cations such as iron. These cations are essential for *Listeria* to grow. Shelef (1994) suggested that it could also be possible that the effects of lactate on C. botulinum are associated with chelation of cations such as iron.

Meat Color

Color of foods plays an important role in determining our acceptability of food. For example, for a fully cooked poultry meat we expect it to be free of pinkness, unless it is a cured product. Therefore, color of meat is very important to the meat industry where it is used by the consumer as one measure of quality in selecting meat for purchase (Froning, 1995; Seideman et al., 1984; Govindarajan, 1973; Solberg, 1970). The primary heme pigments found in poultry muscle include myoglobin, hemoglobin and cytochrome C (Lawrie, 1991). In the blood, hemoglobin is the primary pigment, while in the muscle myoglobin predominates. Cytochrome c is found in the mitochondria. The appearance of the poultry meat is mainly contributed by the chemical state and quantity of myoglobin (Froning, 1995). However, other factors such as pH, water holding capacity (WHC), diet, stress factors, temperature and storage time could also play a significant role in determining the color of meat.

Janky and Froning (1973) found that denaturation of turkey meat myoglobin was increased by lowering the pH. Spray dried egg albumen of pH 7 to 8 increased the pinkness of ground turkey meat when used as meat binder (Froning et al., 1968). Turkey breast that exhibited lower pH was found to have lighter color, and also had lower gel strength, and higher cooking lost than meat with higher pH and darker color (Barbut, 1993).

As with pork meat, poultry meat also suffers a condition called pale soft exudative (PSE) (van Hoof, 1979; Froning et al., 1978). Pork muscles with pH below 5.8 within 45 min postmortem are regarded as PSE (Renerre, 1990). Turkeys that were exposed to stress (heat stress or free struggling) prior to slaughter showed rapid pH decline (Froning et al., 1978). In swine, high temperatures immediately prior to slaughter induced a rapid pH decline due to accelerated post-mortem glycolysis, thus decrease the color intensity of the meat (Sayre et al., 1963). The color intensity of meat is influenced by pH and the structure of the meat. The low pH is caused by lactic acid buildup due to anaerobic breakdown of glucose and glycogen. The low pH will also cause the muscle structure to open up, water is released, and the meat surface looks wet, thus reflect more light and appear lighter in color (Seideman et al., 1984; MacDougall, 1982). Pale, soft, exudative (PSE) meat also has poor water holding capacity (WHC). Tissues with poor WHC undergo greater moisture loss, thus greater weight loss during storage due to shrinkage (Forrest, et al., 1975). Prolongation of high temperature at low pH causes muscle proteins to denature, thus losing their ability to hold water, and giving rise to PSE conditions (Scopes, 1964). However, at high pH, muscle fibres are more tightly packed together as a result of increased WHC of muscle protein, thus the meat surface does not reflect light and causes the meat to look darker (Renerre, 1990). This leads to the condition known as dark-cutting meat, especially in beef.

Concentration of greater than 1.25% lactic acid resulted in unacceptable discoloration of meat, while concentration of greater than 2% gave rise to sour flavor of the treated meat (Mendonca et al., 1989; Woolthuis and Smulders, 1985). Sodium lactate has fewer color and flavor problems than lactic acid (Brewer et al., 1995).

Sodium lactate of up to 3% level (Brewer et al., 1995; Lamkey et al., 1991) or 2% potassium lactate (Bradford et al., 1993) did not affect initial pH of pork products. Moreover, Bradford et al. (1993) did not observe any significant changes in the pH values over the 12 days storage period. However, Brewer et al. (1995) observed an increase in pH over time. Samples containing 3% sodium lactate had lower pH than those with 1% or 2% sodium lactate (Brewer et al., 1995). Contrary to Brewer et al. (1995), Papadopoulos et al. (1991b) found that significant pH decreased with decreasing sodium lactate concentration in cooked, vacuum packaged beef top rounds injected with 0, 1, 2, 3, and 4% sodium lactate, but with maximum pH occurring in cooked roasts containing 3% sodium lactate. Papadopoulos et al. (1991b) observed that the pH of the cooked beef roast decreased significantly during storage with no interaction between treatment level and storage time. Increasing the levels of sodium lactate resulted in lower aerobic plate counts and higher lactic acid concentration for the beef roast (Papadopoulos et al.,1991b). Sometimes reduced pH could be observed over time of refrigerated storage, especially vacuum-packaged products due to inhibition of the growth of acid-producing bacteria (Brewer et al., 1992; Brewer et al.,1991). Egbert et al. (1992) observed that pH of beef patties containing 2% or 3% potassium lactate did not change during refrigerated storage, however, patties with 0% or 1% sodium lactate had increased pH.

A 3% concentration of sodium lactate at pH 7.05 and 6.50 reduced surface discoloration in chubs of fresh sausage and extended shelf life from 10 to 20 days. Under retail conditions, sodium lactate did not affect lean color (Lamkey et al., 1991). Red color of ground pork meat was best preserved by 2% or 3% sodium lactate (Brewer et al., 1995). Papadopoulos et al. (1991c) in their study with cooked, vacuum packaged beef top rounds with 0, 1, 2, 3, or 4% sodium lactate found that increasing sodium lactate resulted in darker, redder color of the cooked product.

Papadopoulos et al. (1991c) also observed that the L* value (indication of lightness where 100 and 0 represent white and black color, respectively) did not indicate any significant interaction between treatment and storage time. The L* values fluctuated during storage, but there was no apparent pattern. When the data were pooled over time and processing days, the L* values decreased with increasing sodium lactate up to 2%, and beyond that it did not affect lightness of the product. However, Brewer et al. (1991) indicated that the L* value of fresh pork sausage was not affected by the level of sodium lactate (1, 2, or 3%), but was affected by time of storage. The L* value increased at day 14 and decreased at day 17, but at day 21 the value did not significantly differ from day 0 (Brewer et al., 1991). With the addition of organic acids to fresh, vacuum packaged pork, Mendonca et al. (1989) found that the L* value decreased over time.

Papadopoulos et al. (1991c) observed that the a* and b* values which measure chromaticity (positive, negative, and 0 values indicate redness, greenness, and grayness, for a*, and yellowness, blueness, grayness, for b*, respectively) had no interaction between sodium lactate and storage time. When the data were pooled over time, redness was lower in the control than in the treated samples. Papadopoulos et al. (1991c) observed that increasing sodium lactate beyond 1 to 2% did not significantly affect color. The researcher suggested that myoglobin color may be affected by lactate ion concentration whereby when the cellular ionic concentration reached a particular point, the myoglobin may have denatured to a specific degree, beyond that point the color remains the same regardless of increasing the level of sodium lactate. Similarly, Brewer et al. (1991) and Mendonca et al. (1989) reported that neither sodium lactate nor time of storage had an effect on the a* value.

As for the b* value, yellowness was inversely related to the sodium lactate level where beef rounds treated with 2 to 4% sodium lactate were less yellow than those treated with 0 or 1% sodium lactate (Papadopoulos et al., 1991c). Brewer et al. (1991) indicated that fresh pork sausage with 1, 2, or 3% sodium lactate did not affect b* value, but the value decreased to a constant level during the first 7 days of refrigerated storage, thus indicating that sausage became more yellow with extension of the storage time. The mechanism for cooked muscle color change by sodium lactate is not known (Papadopoulos et al., 1991c). In another study, Papadopoulos et al. (1991b) demonstrated that higher sodium lactate resulted in lower pH over time, thus increased the acidity of the product. It has been well established that muscle with lower pH has lighter color, and vice versa.

The objectives of this research were 1) to determine the effect of sodium diacetate (NaD) and/or sodium lactate (NaL) on the total psychrotrophic microflora, and 2) to ascertain the effects of sodium diacetate and/or sodium lactate treatments on sensory, chemical and physical characteristics of the restructured turkey steaks processed with the Fibrimex® binding system.

MATERIALS AND METHODS

Materials

Fibrimex® was obtained from FNA Foods Inc., Calgary, Alberta, Canada. It is composed of fibrinogen and thrombin. These two components were individually packed, and maintained in frozen storage until needed. Sodium lactate (60% solution of sodium lactate)(Purasal®S) was supplied by PURAC America Inc., Lincolnshire, IL 60069, and sodium diacetate (71% solution of sodium diacetate) by CHR Hansen, Inc., Gainesville, Florida 32606. Whole turkey breast meat samples were purchased from a single supplier from Jacksonville, Florida. The supplier obtained the meat from Rocco Turkeys, Inc., Dayton, Virginia 22821. All the turkey breast meat samples were in a frozen state upon arrival at the Meat Research Laboratory, Department of Animal Science, University of Florida, Gainesville, Florida 32611. The meat samples were wrapped in plastic, and boxed. Each box contained 40 lbs boneless/skinless turkey breast meat. Upon arrival, the turkey meat samples were immediately stored at -30°C. The restructured turkey product was processed in the Meat Science Processing Laboratory.

Preparation of Fibrimex®

The experimental design is presented in Table 1. A 6% Fibrimex® binding solution was prepared containing a ratio of 20:1 fibrinogen:thrombin. The fibrinogen and thrombin were thawed for 1 hour by immersion in warm water (26°C) in a water bath (Precision Scientific, Chicago, IL 60647). The thawed fibrinogen was mixed thoroughly to insure even distribution of the protein in the package. Prior to combining the fibrinogen and thrombin, sodium lactate (NaL) and sodium diacetate (NaD) were incorporated into the restructured turkey breasts at levels of 1.5% or 2.0%, and 0% or 0.1%, respectively. A control was prepared containing no sodium lactate or sodium diacetate. This experiment was replicated three times at different occasions. The flowchart for processing of the restructured turkey breast steaks is presented in Figure 1.

Processing of Restructured Turkey Breast

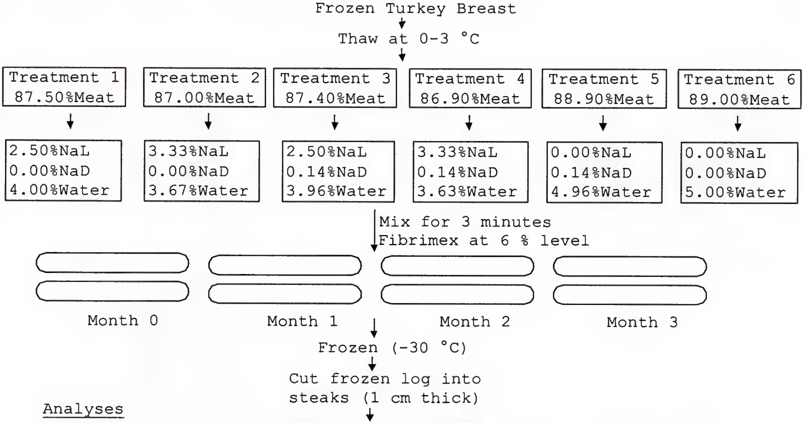
The frozen whole turkey breasts were thawed in a cooler (0 to 3°C) for 3 days before being further processed. On the processing day, the whole turkey breasts were cut into 5 cm thick

Table 1. Formulations for restructured turkey steaks from restructured turkey breasts made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Ingredients	Treatments					
	1	2	3	4	5	6
Turkey breast, %	87.50	87.00	87.40	86.90	88.90	89.00
Sodium lactate[a] (NaL), %	2.50	3.33	2.50	3.33	0.00	0.00
Sodium diacetate[b] (NaD), %	0.00	0.00	0.14	0.14	0.14	0.00
Water, %	4.00	3.67	3.96	3.63	4.96	5.00
Fibrimex®, %	6.00	6.00	6.00	6.00	6.00	6.00

[a] From Purasal 60% solution.

[b] From sodium diacetate 70% solution.



Analyses

Microbiology: Psychrotrophic counts and pH.

Meat Quality: Water activity, surface pH, binding integrity score, binding score, binding strength, thaw loss, cooking yield, sensory, 2-thiobarbituric acid test, chemical compositions

Figure 1. Processing of restructured turkey steaks with sodium diacetate (NaD) and/or sodium lactate (NaL).

strips. The cut was made parallel to the muscle fibre. For each treatment, 18 kg of 5 cm thick turkey breast strips were weighed and placed in an individual container.

Based on the formulation from Table 1, for each treatment, a solution mixture was prepared. For treatment 1, 2, 3, 4, 5, and 6, the solution mixtures were composed of 1.5% NaL + 0% NaD, 2.0% NaL + 0% NaD, 1.5% NaL + 0.1% NaD, 2.0% NaL + 0.1% NaD, 0% NaL + 0.1% NaD, and 0% NaL + 0% NaD, respectively. These solutions were formulated to contain 5% water. For the control treatment, the solution contained only 5% water without the addition of NaL or NaD.

Initially, half of the treatment solution was added to the meat, then mixed (Model 60 Keebler, Chicago, IL) for 1.5 min. The remaining solution mixture was then added to the meat, and mixed again for 1.5 min. The total mixing time was 3 min. The treated meat was divided into 2.3 kg batches. Each batch of meat was coated with Fibrimex® at a level of 6%. Due to rapid formation of fibrin clot (i.e., 10 minutes), thrombin was added to the fibrinogen solution at the point of coating the meat. The combination of fibrinogen to thrombin was carried out based on the 2.3 kg batch of meat to be stuffed into a casing tube which formed one meat log. Therefore, for each treatment, 2 meat logs were allocated for each storage study (0, 1, 2, and 3 months).

Once the meat was coated with Fibrimex® (ratio of 20 parts fibrinogen to 1 part thrombin), the coated meat was quickly stuffed (Aligned Grain Stuffer (AGS), StanFos, Inc., Edmonton, AB T6B 2V2-1000, Canada) into a tubular casing, 12 cm in diameter by 94 cm in length(Package Concepts & Materials Inc., Greenville, South Carolina 29607). The end of the tubular casing was then clipped (Tipper Tie, Rheem Manufacturing Company, Apex, North Carolina 27502). The AGS system was on loan from FNA Foods Inc., Calgary, Alberta T2W 3M6, Canada. The stuffed meat was packaged in cardboard boxes, and stored in a blast freezer (-30 °C) until evaluated.

On each sampling day, the meat was sliced (Butcher Boy Bench Saw Model SA20, Lasar Manufacturing Company, Inc., Los Angles, CA 90059) to 1.0 cm thick steaks, placed on a styrofoam tray (Tenneco Packaging, Northbrook, IL 60062) containing an absorbent pad (Dri-Loc 40, Sealed Air Corporation, Saddle Brook, NJ 07663), wrapped with PVC film, stored in cardboard boxes. The boxes were stored in a walk-in cooler (0°C) for evaluation of psychrotrophic microflora growth, color, water activity, pH and surface pH, binding score, and binding integrity score.

pH Measurement

The pH of each sample was obtained from the 1:10 dilution prepared for the microbiological assay (Kempton and Bobier, 1970). Duplicate samples of 10 gm from each replicate in a treatment were mixed with 90 mL of sterile deionized water, and blended for 1 min in a stomacher (Model STO-400, Tekmar Co., Cincinnati, OH 45222). The change in the surface pH of the restructured turkey steaks was also determined using a flat surface electrode (Catalogue Number 13-620-289, Accumet Engineering Corporation, Hudson, MA 01749) attached to a portable pH meter (Oyster, Extech Instruments Corporation, Waltham, MA 02451). Three samples from each replicate were obtained for surface pH evaluation.

Color Measurement

A portable colorimeter (Minolta Chroma Meter CR100, Minolta, Osaka 541, Japan) was utilized to obtain objective data for color of the restructured turkey steaks. Before each sampling period, the machine was calibrated as recommended by the manufacturer. Triplicate samples per treatment were evaluated for 'L' (degree of lightness), 'a' (degree of redness), and 'b' (degree of yellowness) values. The value of 'L' represented lightness, where zero indicated black and 100 absolute white. The 'L' value indicated the overall reflectance of the sample. Three samples from each replicate were obtained for color measurement.

Yield Parameters

Six samples were taken from each treatment for sensory evaluations and cooking yield determination. Frozen samples were weighed and thawed in a chiller (3°C) overnight. The following day, each package was wiped with a paper towel to remove surface moisture, and weighed to determine the thaw loss percentage. After cooking, the meat samples were weighed to determine cooking yield percentage.

Sensory Analyses

Trained panelists were used in this study. The panelists were students and staff from the Animal Science Departments, University of Florida, Gainesville, Florida. A minimum of 8 panelists was employed in this study. The panelists were trained for juiciness, off-flavors, tenderness, and flavor intensity of the restructured turkey breast. Panelists were trained for juiciness of the restructured turkey steak by cooking the product at different levels of doneness. For off-flavors, panelists were trained by tasting steaks incorporated with 2% sodium lactate and 5% vinegar. As for flavor intensity of turkey meat, the panelists were presented with different strengths of turkey broth. The broth was prepared using bones, back, and thigh meat from turkey. The training session was conducted once at one week before the actual testing date.

Steaks were cooked in an electric skillet (Catalogue Number 72630, The West Bend Company, West Bend, WI 53095) for a total of 5 min (2½ min on each side). Each cooked steak was divided into 4 sections, and each panelist received one section. Each panelist also received crackers and plain bottled water (room temperature) (Publix, Lakeland, Florida 33802) along with the meat samples. Panelists were instructed to eat crackers and drink plain water between each sample to clear their palate, and pause for 20 seconds between samples.

The parameters that were considered for sensory analysis included juiciness, tenderness, off-flavor, and turkey flavor intensity. Eight-point scales were employed for juiciness (8= extremely juicy, 7 = very juicy, 6 = moderately juicy, 5 = slightly juicy, 4 = slightly dry, 3 = moderately dry, 2 = very dry, and 1 = extremely dry), and turkey flavor intensity (8 = extremely intense, 7 = very intense, 6 = moderately intense , 5 = slightly intense, 4 = slightly bland, 3 = moderately bland, 2= very bland, and 1 = extremely bland). A 6-point scale was employed for off-flavor (6 = none detected, 5 = threshold, barely detected, 4 = slightly off-flavor, 3 = moderate off-flavor, 2 = strong off-flavor, and 1 = extreme off-flavor).

Binding Measurements

Objective measurements for binding strength of the restructured steaks were conducted for frozen storage at 1, 2, and 3 months storage using the grip method. Grips (Catalogue Number 2710-002, Instron Corporation, Atlanta, GA 30340) were attached to the Instron machine (Model 1011, Instron Corporation, Atlanta, GA 30340). A crosshead speed of 200 mm/min, and a 50 kg load cell were used. Four raw steaks (1.5 cm thick and 7.5 cm in diameter) from each treatment were analyzed to determine binding strength of the restructured turkey steaks. Only steaks with centrally located bind junction were selected for the binding strength using the Instron machine. Each steak was cut into 2.5 cm in width and 7.5 cm in length strips. The grip was applied to each end of the strip, and the peak force was recorded by pulling the strip apart until the bind junction was completely separated. Peak force in kilograms was the unit used to measure strength of the bond between the meat pieces.

Binding strength and integrity of the steaks were also evaluated for the simulated retail display steaks. Scores were assigned based on the amount of separation between the bond

(5=100% intact, 4=75% intact, 3=50% intact, 2=25% intact, and 1=0% intact or 100% separation). For the binding score, each steak was held on the second finger for 10 sec, while for the integrity test score, the steaks were observed for breaks in the bind junctions. Three steaks were evaluated for each replicate within each treatment.

Microbiological Examination

Microbiological and pH measurements were conducted on the same day the meat logs were sliced. These measurements were conducted at two day intervals for a period of 10 days. Two duplicate samples were obtained from each replicate where it was plated twice for each duplicate. A 10 gm sample was diluted with 0.1% sterile peptone diluent to obtain a 10^{-1} dilution from which serial dilutions were prepared. Serial dilutions were prepared by transferring 1.0 mL aliquot of the sample diluent to 9 mL of sterile 0.1% peptone (DIFCO Laboratories, Detroit, MI 48232). The extent of the serial dilutions depended on the bacterial counts from the previous sampling period. Initially, higher dilutions were prepared to assess the initial bacterial load in the samples.

Psychrotrophic count was conducted using Petrifilm method for total plate count (Aerobic Count Plates, 3M, St. Paul, Minnesota 55144). Each plate was labeled with the desired dilutions, plated with 1.0 mL of the appropriate sample dilution, and incubated at 20°C for 5 days. The counts were reported as colony forming units (CFU) per gm of sample.

Chemical Analyses

Water activity (Aw) was measured with Aqualab model CX2 (Decagon Devices, Inc., Pullman, WA 99163) water activity measuring device. Three samples were obtained from each replicate within each treatment. Before measuring water activity, the instrument was first calibrated using saturated sodium chloride solution as instructed by the manufacturer. Samples were placed in plastic sample dishes that were specifically designed for the instrument. Once each sample was placed in the sample drawer, the drawer was immediately closed and the knob was turned from "Open/Load" to "Read". If sample dish was placed correctly in the sample drawer, a beeping sound was produced by the instrument and Aw was measured. The Aw result was displayed on the digital readout after approximately five minutes. Prior to reading, samples were placed in sample dishes and covered with the sample dish cap to avoid dehydration while waiting for its Aw to be measured.

Restructured steaks from the frozen storage study were also evaluated for oxidative rancidity using 2-thiobarbituric acid (TBA) test as described by Rhee (1978). Duplicate 10 gm samples were blended in 47.5 ml cold deionized water and 5 ml antioxidant suspension (0.5% [W/V] propyl gallate and 0.5% [W/V] EDTA in distilled water) for 30 sec. The homogenate was quantitatively transferred by rinsing with an additional 45 ml cold deionized water into a Kjeldhal flask containing 2.5 ml of 4 M HCl. The homogenate was distilled to yield 50 ml of distillate. Duplicate 5 ml aliquots of distillate were mixed with 5 ml of TBA reagent (0.02 M 2-thiobarbituric acid in 90% [V/V] glacial acetic acid) and heated in boiling water for 35 min. After heating, the samples were cooled in running tap water for 10 min, and the absorbance was read at 535 nm using a Lambda 3 UV/VIS spectrophotometer (Perkin-Elmer Corporation, Oak Brook, IL 60521). The absorbance was multiplied by 7.042 to convert to mg of malonaldehyde per 1000 g of meat. The conversion factor was obtained from running a standard.

For proximate analysis (protein, fat, moisture, and ash) three steaks were ground per treatment. Each ground sample was analyzed in duplicate. The analyses were conducted as outlined in the Official Methods of Analysis of the AOAC (AOAC, 1984).

Statistical Analyses

The incorporation of sodium diacetate and/or sodium lactate in the Fibrimex® study follows a 2x3 factorial design (2 levels of sodium diacetate 0% and 0.1%; 3 levels of sodium lactate 0%, 1.5%, and 2.0%). SAS® software program (SAS Institute, 1990) was used to determine significance of differences among the treatments at a P-value of 0.05. The procedure PROC MIXED or PROC GLM from SAS (SAS Institute, 1990) was used for the analyses of repeated measures. For comparisons among treatments, CONTRAST statements were used in the analyses. With respect to meat and poultry products, limited research has been done on sodium diacetate. In the present study, the effects of sodium diacetate on restructured turkey steaks were compared to sodium lactate, combination of sodium diacetate with sodium lactate, and untreated steaks (control). Besides sodium diacetate, research on sodium lactate with Fibrimex® has never been reported in literature. Therefore, the effects of sodium lactate on restructured turkey steaks were compared with the combination of sodium diacetate with sodium lactate, and the untreated steaks.

RESULTS AND DISCUSSION

All data discussed are based on steaks that were cut from frozen restructured turkey breasts after storage at -30°C for 0, 1, 2, and 3 months. At each month, the steaks were evaluated for sensory characteristics. The steaks were evaluated after 0, 2, 4, 6, and 8 days storage at 0°C for surface pH, binding integrity score, binding score, and water activity. The steaks were evaluated for total psychrotrophic counts after 0, 2, 4, 6, 8, and 10 days storage at 0°C. Binding strength and 2-thiobarbituric acid (TBA) test were conducted on the steaks cut from frozen restructured turkey breasts after storage at -30°C for 1, 2, and 3 months.

Microbiological Study

Psychrotrophic Counts

Microbiological analyses of the fibrinogen samples were carried out during the initial stage of the experiment. From the analyses, fibrinogen samples that were purchased from FNA Foods

Inc., Calgary Alberta, Canada were not processed aseptically. The average total psychrotrophic count was found to be 4.6 $\log_{10}$ cfu/ml. The initial average total bacterial count of the turkey breast meat was found to be 4.6 $\log_{10}$ cfu/g. Therefore, the fibrinogen and the turkey meat had similar average total psychrotrophic counts.

Bacterial growth is divided into four phases that include lag phase, logarithmic phase (or exponential phase), stationary phase, and death phase (Forrest et al., 1975). During lag phase the bacteria that are initially present would not grow unless favorable conditions exist. Therefore, any food additives used according to the governmental regulations, which could increase the lag phase would be beneficial to the food industry.

Psychrotrophic counts for restructured turkey steaks containing no sodium lactate and/or sodium diacetate increased rapidly when compared to steaks with sodium diacetate or combinations of sodium diacetate and sodium lactate (Figure 2). The control steaks reached 7.1 $\log_{10}$ cfu/g at 6 days of storage which generally means spoiled meat (Brewer et al., 1995). When 1.5% sodium lactate was added, there was a decrease in the total psychrotrophic counts from day 4 to day 6, but again it showed a similar growth pattern as that of the control group (Figure 2). Increasing the level of sodium lactate to 2.0% reduced the total

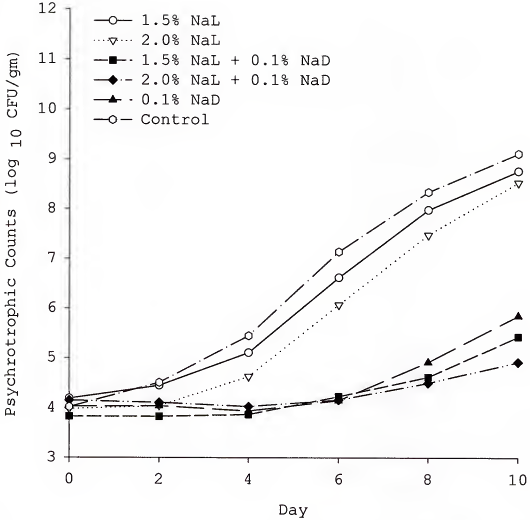


Figure 2. Psychrotrophic counts of steaks sliced from restructured turkey breast made with Fibrimex, treated with sodium lactate (NaL) and/or sodium diacetate (NaD), and stored for 10 days at 0°C.

psychrotrophic count of the steaks over 10 days storage at 0°C. Nevertheless, with the addition of 1.5% or 2.0% sodium lactate to the restructured turkey steaks, the total psychrotrophic counts at day 8 were 8.0 and 7.5 $\log_{10}$ cfu/g, respectively (Figure 2).

A different trend from that of sodium lactate was observed for sodium diacetate (Figure 2). Sodium diacetate at 0.1% level significantly ($P<0.05$) extended the lag phase growth of the bacteria when compared with steaks treated with either 1.5% or 2.0% sodium lactate (Table 2). The average total psychrotrophic count at day 10 for steaks treated with 0.1% sodium diacetate alone was 5.9 $\log_{10}$ cfu/g. This count was significantly lower than the steaks treated with either 1.5% or 2.0% sodium lactate, and the control group, which had counts of 8.8 $\log_{10}$ cfu/g, 8.5 $\log_{10}$ cfu/g, and 9.1 $\log_{10}$ cfu/g, respectively at day 10 of storage. Steaks treated with 0.1% sodium diacetate alone had an extension in lag phase of up to 4 days. In fact, in the first 4 days of storage, slight decline in the growth of psychrotrophic organisms for steaks treated with 0.1% sodium diacetate or with combinations of sodium diacetate and sodium lactate were observed (Figure 2). After the short decline, there was a slight increase in the average total psychrotrophic count from day 4 to day 6, followed by a gradual increase in the counts from day 8 to day 10 (Figure 2).

Table 2. Mean for total psychrotrophic counts of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage					
	0	2	4	6	8	10
Treatments						
(1) 1.5% NaL	4.19	4.45	5.11	6.62	7.98	8.76
(2) 2.0% NaL	3.98	4.04	4.63	6.07	7.48	8.53
(3) 1.5% NaL + 0.1% NaD	3.83	3.83	3.87	4.23	4.62	5.43
(4) 2.0% NaL + 0.1% NaD	4.15	4.11	4.03	4.16	4.50	4.92
(5) 0.1% NaD	4.03	4.04	3.94	4.15	4.92	5.85
(6) Control	4.02	4.51	5.45	7.14	8.34	9.11
P-values						
Treatment[a]	.2682	.0045	.0001	.0001	.0001	.0001
Comparisons[b]						
1 vs 5	.1376	.0023	.0001	.0001	.0001	.0001
2 vs 5	.7649	.9948	.0001	.0001	.0001	.0001
5 vs 6	.9605	.0006	.0001	.0001	.0001	.0001
5 vs 3,4	.9088	.5597	.8096	.5054	.0314	.0001
1,2 vs 3,4	.3337	.0047	.0001	.0001	.0001	.0001
6 vs 1,2	.5236	.0223	.0001	.0001	.0006	.0038
5,6 vs 1,2,3,4	.5447	.0001	.0001	.0001	.0001	.0001

[a, b] Value significantly different if $P<0.05$.

Even though sodium diacetate when used alone effectively reduced the total psychrotrophic counts, additional reduction ($P<0.05$) in psychrotrophic counts was observed when sodium diacetate was combined with sodium lactate (Table 2). The data demonstrated that sodium lactate and sodium diacetate when used together resulted in a synergistic effect. At day 10, steaks treated with combination of sodium diacetate and sodium lactate had significantly reduced psychrotrophic count when compared with steaks treated with sodium diacetate alone (Table 2). A lag phase period of 4 days were observed for steaks treated with sodium diacetate and sodium lactate combinations.

The increase in the shelf life of meat and meat products by sodium lactate has been widely reported in the literature (Calhoun et al., 1999; Banks et al., 1998; Brewer et al., 1995; Williams et al., 1995; Brewer et al., 1992; Brewer et al., 1991; Stillmunkes et al., 1993; O'Connor et al., 1993; Lamkey et al., 1991; Duxbury, 1988). The extent of shelf life extension has been as much as 2 to 4 days in ground poultry products (Duxbury, 1988). With fresh ground pork, at a microbial count of 10^6 cfu/g, 3.0% sodium lactate extended the shelf life of the product by 12 days when compared to the control sample (O'Connor et al., 1993). Shelf life of catfish fillets treated with 2.0% sodium lactate was extended from 4 to 7 days (Williams et al., 1995). Increasing sodium lactate resulted in bacterial reduction (Papadopoulos et al., 1991b). Moye (1991) investigated the use of sodium diacetate for controlling microbial spoilage of poultry on a laboratory scale study and confirmed its effectiveness under commercial plant conditions. Surface application of sodium diacetate at dusting levels of 1-3 mg/cm^2 (2-6 g/chicken) extended shelf life of whole chickens by approximately 4 days at 2°C (Moye, 1991). Shelf life extensions of over 10 days were achieved with chicken pieces (Moye, 1991).

No documentation was available in the literature concerning shelf life extension of restructured turkey steaks processed with Fibrimex® and treated with sodium lactate and sodium diacetate. This study indicated that sodium lactate treatments at 1.5% or 2.0% resulted in lower psychrotrophic counts when compared to the control. This study also revealed that sodium diacetate, significantly enhanced the antibacterial activity of sodium lactate when used in combination treatments. In fact, sodium diacetate alone at 0.1% significantly ($P<0.05$) reduced the psychrotrophic counts when compared with steaks treated with sodium lactate alone or untreated steaks (control).

Islam et al. (1978) observed that the shelf life of poultry meat ended when the total psychrotrophic counts reached 10^6 to 10^7. However, Barnes (1976) observed that psychrotrophic microflora produced unacceptable off-odor when their population reached 10^7 to 10^8. Other researchers considered that shelf life of meat products ended when the total bacterial counts reached 10^7 where the meat has unacceptable off-odor, and is considered spoiled (Brewer et al., 1995; Jay, 1992; Cunningham, 1979). In this study, the restructured turkey steaks containing 0.1% sodium diacetate or combination of sodium diacetate with sodium lactate had not reached spoilage level ($\log_{10}$ 6.0 cfu/g) at the conclusion of this study (i.e., 10 days at 0°C). It was concluded that treatment with 0.1% sodium diacetate or combination of 0.1% sodium diacetate with either 1.5% or 2.0% sodium lactate has potential for extending shelf life of refrigerated restructured turkey steaks manufactured with Fibrimex® binding system.

pH of Steaks from Microbiological Analyses

The pH values of the sample homogenate and surface pH of steaks stored at 0°C and treated with sodium lactate and/or sodium diacetate throughout the microbiological sampling periods (day 0, 2, 4, 6, 8, and 10) are shown in Figure 3 and Figure 4, respectively. By day 10, all steaks that were treated with either 0.1% sodium diacetate or combined with sodium lactate at either 1.5% or 2.0% level had maintained lower pH of the homogenate than steaks that were not treated or treated with only sodium lactate

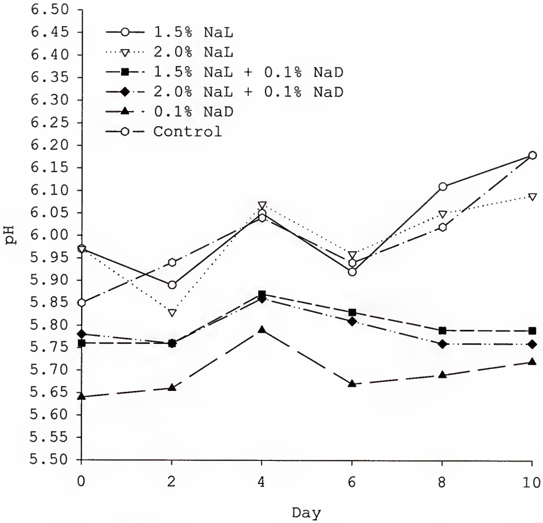


Figure 3. Mean pH values from sample homogenate of steaks treated with sodium lactate (NaL) and/or sodium diactate (NaD), and stored at 0°C for 10 days.

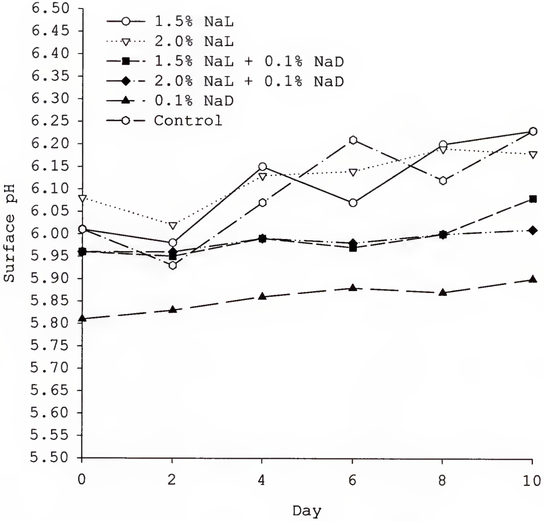


Figure 4. Mean surface pH values for the microbiological samples of the restructured turkey steaks manufactured with Fibrimex, treated with sodium lactate (NaL) and/or sodium diactate (NaD), and stored at 0°C for 10 days.

(Figure 3). Similar pH trends were also observed for the surface pH of the meat (Figure 4). Since sodium diacetate has acidic characteristics its usage caused the pH of the meat to be lowered. Shelef and Addala (1994) observed that minced beef pH decreased from 5.6 to 5.2 with the addition of sodium diacetate. Schlyter et al. (1993b) observed that meat slurries containing 0.3% or 0.5% sodium diacetate had pH of 5.5 and 5.2, respectively. Al-Sheddy et al. (1999) observed that camel meat when treated with sodium acetate had lower pH when compared with the control. The pH of the camel meat at day 12 was similar with day 0 when treated with sodium acetate (Al-Sheddy et al., 1999). Similar observations were also made in this study where steaks treated with either sodium diacetate or combination of sodium diacetate and sodium lactate maintained low pH throughout the 10 days storage.

The restructured turkey breasts when treated with 0.1% sodium diacetate produced steaks that had significantly ($P<0.05$) lower pH (homogenate) when compared with untreated steaks throughout the sampling periods (control) (Table 3). Similar trends were observed between steaks treated with 0.1% sodium diacetate and steaks treated either with 1.5% or 2.0% sodium lactate where the former treatment had significantly lower pH of the homogenate than the later treatments (Table 3). However, the

Table 3. Mean for pH of sample homogenate of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage					
	0	2	4	6	8	10
Treatments						
(1) 1.5% NaL	5.97	5.89	6.05	5.92	6.11	6.18
(2) 2.0% NaL	5.97	5.83	6.07	5.96	6.05	6.09
(3) 1.5% NaL + 0.1% NaD	5.76	5.76	5.87	5.83	5.79	5.79
(4) 2.0% NaL + 0.1% NaD	5.78	5.76	5.86	5.81	5.76	5.76
(5) 0.1% NaD	5.64	5.66	5.79	5.67	5.69	5.72
(6) Control	5.85	5.94	6.04	5.94	6.02	6.18
P-values						
Treatment[a]	.0037	.0239	.0295	.0028	.0001	.0001
Comparisons[b]						
1 vs 5	.0001	.0004	.0003	.0010	.0001	.0001
2 vs 5	.0001	.0049	.0001	.0002	.0001	.0001
5 vs 6	.0065	.0001	.0003	.0003	.0001	.0001
5 vs 3,4	.0494	.0583	.1990	.0208	.1443	.3196
1,2 vs 3,4	.0005	.0208	.0001	.0208	.0001	.0001
6 vs 1,2	.0813	.1401	.7763	.9308	.3067	.3750
5,6 vs 1,2,3,4	.0001	.0001	.0001	.0001	.0001	.0001

[a, b] Value significantly different if $P<0.05$.

treatment groups with the addition of only sodium lactate did not differ significantly in the pH of the homogenate when compared with the control group at all sampling periods (Table 3). The decrease in the pH of the homogenate for steaks treated with both sodium lactate and sodium diacetate were significantly different ($P<0.05$) when compared with steaks treated with sodium lactate (Table 3). Throughout the sampling periods, the pH of the homogenate of all steaks for treatment groups with the addition of sodium lactate and sodium diacetate were higher compared with the treatment that used only sodium diacetate (Figure 3).

An almost similar phenomena occurred with the surface pH of the steaks that were treated with sodium lactate and/or sodium diacetate. Significant changes among the treatments were observed after day 2 (Table 4). At earlier storage periods (day 0 and 2), the surface pH was not significantly different ($P>0.05$) among the treatments, however, as the storage time progressed, the surface pH of the steaks increased for steaks treated with only sodium lactate or control (Figure 4). However, steaks that were treated with sodium diacetate or combination of sodium diacetate with sodium lactate maintained lower surface pH (Figure 4). Shelef and Addala (1994) suggested that the antimicrobial effect of sodium diacetate was attributed primarily to the diacetate and not the lowered pH. It was also observed that sodium diacetate

Table 4. Mean for surface pH from microbiological analyses of steaks (stored at 0°C for 0 to 10 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage					
	0	2	4	6	8	10
Treatments						
(1) 1.5% NaL	6.01	5.98	6.15	6.07	6.20	6.23
(2) 2.0% NaL	6.08	6.02	6.13	6.14	6.19	6.18
(3) 1.5% NaL + 0.1% NaD	5.96	5.95	5.99	5.97	6.00	6.08
(4) 2.0% NaL + 0.1% NaD	5.96	5.96	5.99	5.98	6.00	6.01
(5) 0.1% NaD	5.81	5.83	5.86	5.88	5.87	5.90
(6) Control	6.01	5.93	6.07	6.21	6.12	6.23
P-values						
Treatment[a]	.1039	.1445	.0174	.0008	.0002	.0005
Comparisons[b]						
1 vs 5	.0011	.0279	.0001	.0001	.0001	.0001
2 vs 5	.0001	.0081	.0001	.0001	.0001	.0001
5 vs 6	.0010	.1651	.0001	.0001	.0001	.0001
5 vs 3,4	.0047	.0498	.0003	.0075	.0012	.0038
1,2 vs 3,4	.0477	.3000	.0001	.0001	.0001	.0001
6 vs 1,2	.5253	.2125	.0541	.3366	.0555	.8009
5,6 vs 1,2,3,4	.0002	.0850	.0001	.0001	.0001	.0001

[a, b] Value significantly different if P<0.05.

effectively reduced the pH of sodium lactate, thus when used in the meat it enhanced sodium lactate's antibacterial properties. The low pH for steaks treated with either 0.1% sodium diacetate or combination of 0.1% sodium diacetate with 1.5% or 2.0% sodium lactate throughout the 10 days storage could have affected the growth of spoilage microorganisms, thus, extending the shelf life of the product. Williams and Phillips (1998) observed that sodium lactate with pH adjusted to 5.5 and 5.0 were effective in retarding growth of spoilage microflora on chicken breast meat.

Meat Quality

Water Activity

The changes in water activity for restructured turkey breast steaks that were treated with sodium diacetate and/or sodium lactate, and stored at 0°C for 8 days for each frozen storage period (0, 1, 2, and 3 months at -30°C) are shown in Figure 5. Restructured turkey breasts kept at all storage conditions that were either treated with 0.1% sodium diacetate or left untreated (control), produced steaks that had higher water activity when compared with other treatments (Figure 5).

The water activity measurement for the steaks for all treatments had very little change throughout the storage periods

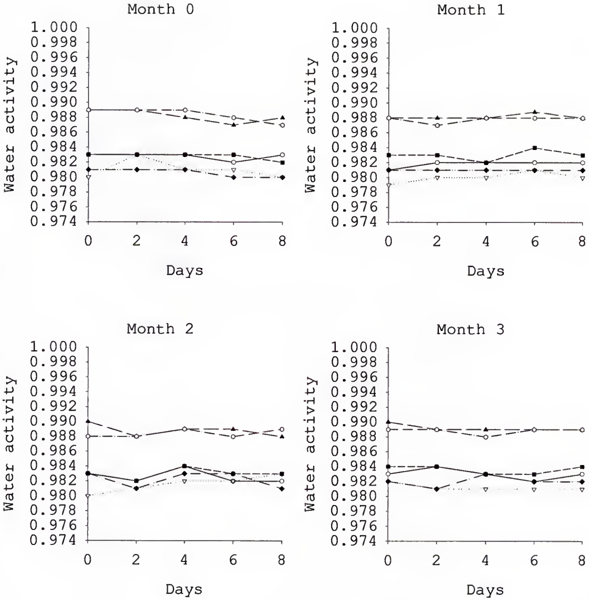


Figure 5. Mean water activity values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C. (—○— 1.5% NaL, ···▽·· 2.0% NaL, --■-- 1.5% NaL + 0.1% NaD, —◆-- 2.0% NaL + 0.1% NaD, —▲— 0.1% NaD, —◇— Control).

(Table 5). There was no 2 way interaction effect between treatment and month of storage for water activity. Similarly, there was no significant 3 way significant effect among treatment, month, and day of storage. Steaks treated with 0.1% sodium diacetate did not differ significantly in the water activity when compared with steaks that were not treated (Table 6). However, steaks treated with 0.1% sodium diacetate had significantly (P<0.05) higher water activity when compared with steaks treated with either 1.5% or 2.0% sodium lactate (Table 6). Besides, the treatment groups for steaks with the addition of sodium lactate and sodium diacetate were found to have significantly (P<0.05) lower water activity than the steaks that were treated with only sodium diacetate (Table 7). Similarly, the treatment groups for steaks treated with only sodium lactate had significantly (P<0.05) lower water activity when compared with the control group (Table 7). The ability of sodium lactate to lower product water activity has been well documented (Maca et al., 1997a; Weaver and Shelef, 1993; Chen and Shelef, 1992; Duxbury, 1988). Other than sodium lactate, Chen and Shelef (1992) observed that potassium and calcium lactate also decreased the water activity.

Since sodium diacetate increased water activity of the steaks, restructured turkey breasts when treated with combination of sodium lactate and sodium diacetate produced steaks that had

Table 5. Slope values for water activity (Aw) of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex®, and treated with sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	-0.00019*	-0.00010	-0.00030
	0.1	-0.00014	-0.00008	-0.00006
1	0	-0.00001	0.00007	0.00013
	0.1	-0.00003	0.00001	-0.00003
2	0	0.00001	-0.00003	0.00028*
	0.1	-0.00011	0.00001	-0.00010
3	0	0.00001	-0.00013	-0.00009
	0.1	-0.00007	0.00005	-0.00003

* Significant at $P<0.05$.

Table 6. Least square mean values* of water activity (Aw) for restructured turkey steaks made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Sodium diacetate level (%)	Sodium lactate level (%)		
	0	1.5	2.0
0	0.9883a	0.9826b	0.9809d
0.1	0.9885a	0.9831c	0.9814e

[*] Means bearing the same letter are not significantly different ($P>0.05$).

Table 7. P-values of comparisons for water activity (Aw) of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Comparisons[a]	P-values[b]
5 vs 3,4	0.0001
1,2 vs 3,4	0.0034
6 vs 1,2	0.0001
5,6 vs 1,2,3,4	0.0151

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

significantly higher water activity when compared with steaks that were treated with sodium lactate only (Table 7). The effect of sodium diacetate on the water activity was significantly higher for steaks treated with sodium diacetate in the presence of sodium lactate when compared with steaks treated with sodium diacetate in the absence of sodium lactate (Table 7). Overall, in all the treatments, the water activity was greater than 0.9, thus, from a practical standpoint, spoilage bacteria would still be able to grow in the product. Even though there were some significant changes among the treatments, the differences in the water activity were very small, and in the real world situation, such changes would most likely be insignificant. Weaver and Shelef (1993) observed that addition of 4% sodium lactate only decreased the water activity of the pork liver sausage by less than 0.01 unit, thus not sufficient to account for the antilisterial activity of this salt. In an earlier work, Chen and Shelef (1992) also observed a slight decrease in the water activity which could not account for the antilisterial activity of this salt.

Surface pH

The changes in surface pH for the steaks over 8 days storage at 0°C for each frozen storage period (0, 1, 2, and 3 months at -30°C) are indicated in Figure 6. To study the pattern of the

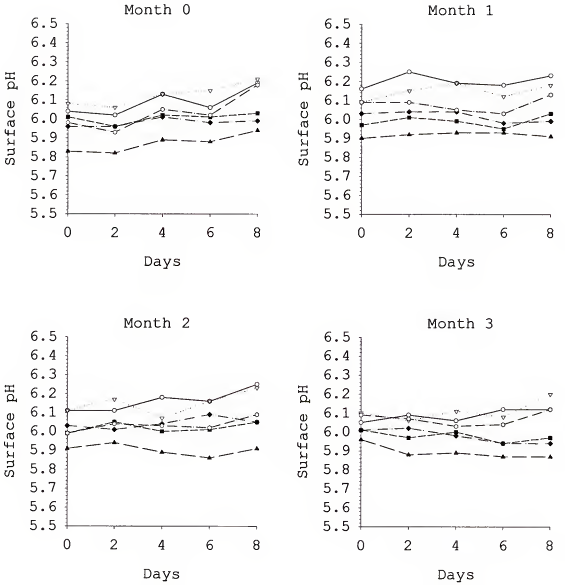


Figure 6. Mean surface pH values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C.(—○— 1.5% NaL, ▿ 2.0% NaL, —■— 1.5% NaL + 0.1% NaD, —◆— 2.0% NaL + 0.1% NaD, —▲— 0.1% NaD, —◇— Control).

surface pH, statistical analysis was conducted to determine the slope for each treatment. Table 8 shows the slopes for the surface pH of steaks stored at different storage periods. There were slight upward and downward trends among the treatments for the surface pH. Even though there were some statistically significant changes during the 8 days storage, however, the changes were very slight, and practically these changes were not significant. Bloukas et al. (1997) observed that addition of 2.0% sodium lactate maintained at almost constant pH through the 6 week storage of frankfurters kept under vacuum at 4°C. Similarly, Williams et al. (1995) observed similar trends where there were no differences between surface pH for fresh catfish fillets treated with 1.0% or 2.0% sodium lactate with pH adjusted to 5.5 with 1M hydrochloric acid through 8 days storage when compared with the control.

The surface pH of steaks treated with 1.5% sodium lactate did not differ significantly ($P>0.05$) when compared with steaks treated with 2.0% sodium lactate. In fact, both of the treatments had similar pH (Table 9). Similarly, restructured turkey breasts with addition of 0.1% sodium diacetate and 1.5% sodium lactate produced steaks that had similar pH values when compared with steaks that were treated with combination of 0.1% sodium diacetate and 2.0% sodium lactate. However, when sodium diacetate was

Table 8. Slope values for surface pH of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	0.025*	0.018*	0.018*
	0.1	0.014*	0.004	0.005
1	0	0.001	0.003	0.007*
	0.1	0.002	0.003	-0.006
2	0	0.009*	0.017*	0.011*
	0.1	-0.003	0.004	0.006
3	0	0.002	0.007*	0.012*
	0.1	-0.009*	-0.006	-0.011

* Significant at $P<0.05$.

Table 9. Least square mean values* of surface pH for restructured turkey steaks made with Fibrimex® and treated sodium lactate and/or sodium diacetate.

Sodium diacetate level (%)	Sodium lactate level (%)		
	0	1.5	2.0
0	6.05a	6.13b	6.13b
0.1	5.90c	6.00d	6.00d

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* Means bearing the same letter are not significantly different (P>0.05).

combined with sodium lactate at 1.5% and 2.0% level, decreased (P<0.05)(Table 9) in the surface pH of the restructured turkey steaks were observed when compared with steaks treated with only sodium lactate. Sodium lactate has pH values between 5.7 to 8.5 (Grau, 1980), thus addition of sodium diacetate at 0.1% level did not decrease the surface pH drastically. The pH of the sodium lactate used in this study was 7.64. Since sodium lactate has high pH, steaks with the addition of sodium lactate at either 1.5% or 2.0% resulted in significant increased in the surface pH when compared with untreated (control) steaks (Table 9). Besides, the treatment groups with addition of sodium lactate were found to have higher surface pH than the control (Table 10). Similarly, Maca et al. (1997) observed that beef patties treated with 2.0, 3.0, or 4.0% sodium lactate had higher pH when compared with the control sample. Also, cooked liver sausage had an elevated pH when 3.0% sodium lactate was added (Shelef and Potluri, 1995).

Restructured turkey breasts when treated with only 0.1% sodium diacetate produced steaks had the lowest surface pH when compared to all other treatments (Table 9). This is because sodium diacetate has a pH between 4.5 and 5.0 (Food Chemical Codex, 1996; FAO, 1992). Therefore, addition of sodium diacetate to the restructured turkey breasts would decreased the surface pH of the steaks. Nevertheless, when restructured turkey breasts

Table 10. P-values of comparisons for surface pH of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Comparisons[a]	P-values[b]
5 vs 3,4	0.0001
1,2 vs 3,4	0.0001
6 vs 1,2	0.0001
5,6 vs 1,2,3,4	0.0001

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

were treated with combinations of sodium lactate and sodium diacetate, the steaks had significantly higher surface pH when compared with steaks treated with only sodium diacetate (Table 10). The decrease in surface pH was significantly greater for steaks that had been treated with sodium diacetate without the presence of sodium lactate when compared with steaks that were treated sodium diacetate in the presence of sodium lactate (Table 10).

Binding Integrity Score

The binding integrity scores for steaks treated with sodium lactate and/or sodium diacetate, and stored at different storage periods are shown in Figure 7. For most of the storage periods, the changes in the binding integrity scores for the steaks were not affected by the treatments (Table 11). Throughout the storage periods, the steaks were all intact except at month 1 for steaks on day 6 and 8 that were treated with 0.1% sodium diacetate which had some weak binding integrity between the meat pieces (Figure 7). All the treatments had binding integrity scores of 5.0 (fully intact), except at month 1 for steaks treated with 0.1% sodium diacetate which had binding score of 4.78 and 4.83 on day 6 and 8, respectively (Figure 7).

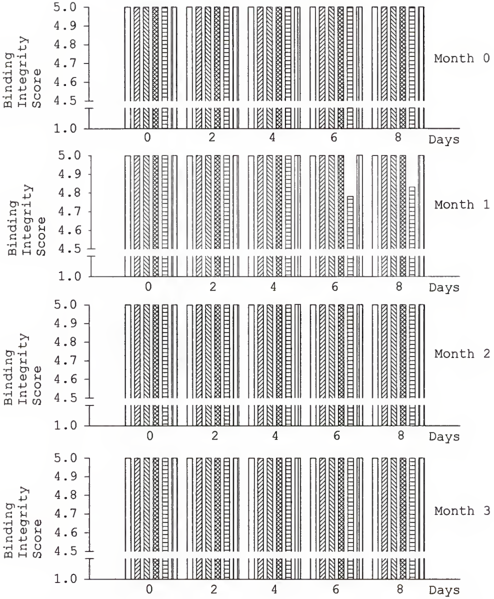

Figure 7. Mean binding integrity scores for steaks stored for 8 days at 0°C that were sliced from restructured turkey breasts made with Fibrimex, treated with sodium lactate (NaL) and/or sodium diacetate (NaD), and stored for at different storage times (0, 1, 2, and 3 months) at -30°C. (▭ 1.5% NaL, ▨ 2.0% NaL, ▧ 1.5% NaL + 0.1% NaD, ▩ 2.0% NaL + 0.1% NaD, ▤ 0.1% NaD, ▥ Control).

Table 11. Slope values for binding integrity scores of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	0.00	0.00	0.00
	0.1	0.00	0.00	0.00
1	0	0.00	0.00	0.00
	0.1	-0.03*	0.00	0.00
2	0	0.00	0.00	0.00
	0.1	0.00	0.00	0.00
3	0	0.00	0.00	0.00
	0.1	0.00	0.00	0.00

* Significant at $P<0.05$.

There was no interaction effect between treatment and month of storage for the binding integrity scores. Steaks that were treated with either sodium lactate, sodium diacetate, or combination of sodium lactate and sodium diacetate behaved the same when compared with steaks that were not treated (Table 12). There were no significant differences for all the comparisons made among the treatment groups (Table 13). Basically, in all the treatments, the meat pieces were held together by the Fibrimex® without falling apart when stored at 0°C for maximum of 8 days. The data demonstrated that 1.5% or 2.0% sodium lactate, 0.1% sodium diacetate, and combination of sodium lactate and sodium diacetate could be used together with the Fibrimex® binding system for production of steaks from restructured turkey breasts without affecting the binding integrity of the product. The Fibrimex® binding capability was not significantly affected by freezing the product for up to 3 months at -30°C.

Binding Score

The binding scores for steaks treated with sodium lactate and/or sodium diacetate at different storage periods are shown in Figure 8. Majority of the restructured turkey steaks were held together by Fibrimex® even when treated with sodium lactate, sodium diacetate, or combination of sodium lactate and sodium

Table 12. Least square mean values* of binding integrity scores** for restructured turkey steaks made with Fibrimex® and treated sodium lactate (NaL) and/or sodium diacetate (NaD).

Sodium diacetate level(%)	Sodium lactate level (%)		
	0	1.5	2.0
0	5.00a	5.00a	5.00a
0.1	4.98a	5.00a	5.00a

* Means bearing the same letter are not significantly different (P>0.05).

** Binding integrity score: 1=100% fall apart and 5=100% fully intact.

Table 13. P-values of comparisons for binding integrity scores of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Comparisons[a]	P-values[b]
5 vs 3,4	0.0639
1,2 vs 3,4	1.0000
6 vs 1,2	1.0000
5,6 vs 1,2,3,4	0.1835

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

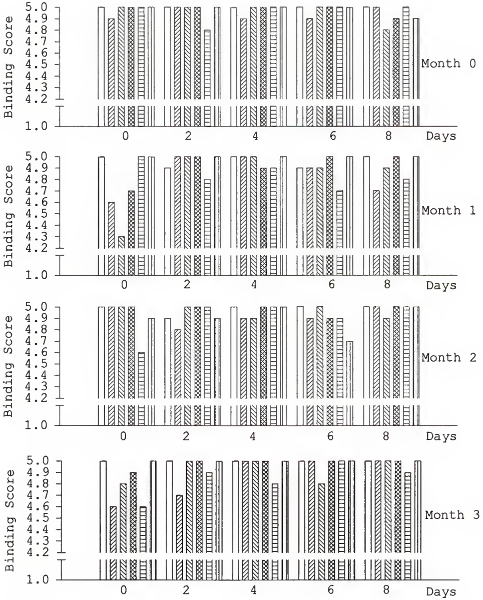

Figure 8. Mean binding scores for steaks stored for 8 days at 0°C that were sliced from restructured turkey breasts made with Fibrimex, treated with sodium lactate (NaL) and/or sodium diacetate (NaD), and stored for at different storage times (0, 1, 2, and 3 months) at -30°C. (▭ 1.5% NaL, ▨ 2.0% NaL, ▧ 1.5% NaL+0.1% NaD, ▦ 2.0% NaL+0.1% NaD, ▤ 0.1% NaD, ▥ Control).

diacetate. Breaks in the joints between the meat pieces however were observed occasionally at certain sampling times for some of the treatments (Figure 8). Nevertheless, the length of the breaks were short, thus not enough to cause the meat pieces to fall apart when handled. In fact, none of the restructured turkey steaks had broken joints more than one-fourth of the total diameter of the steaks (Figure 8).

The changes in the binding scores over time of storage for the restructured turkey steaks kept at 0°C were very small (Table 14). Throughout the 8 days of storage at 0°C, steaks that were treated with sodium lactate and/or sodium diacetate were still able to maintain good binding capability by Fibrimex® comparable to the untreated steaks. Based on the mean value, all the treatments had scores of 4.6 or higher throughout the storage periods. The only exception occurred for steaks on day 0 from restructured turkey breasts that were stored for 1 month at -30°C, and treated with combination of 1.5% sodium lactate and 0.1% sodium diacetate which had binding score of 4.3 (Figure 8). However, the steaks with binding score of 4.3 were still strong enough to hold the meat pieces together without falling apart when handled.

There was no interaction effect between treatment and month of storage for the binding scores. All the steaks that were

Table 14. Slope values for binding scores of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	-0.006	-0.000	0.003
	0.1	0.011	-0.017	-0.006
1	0	0.000	-0.000	0.006
	0.1	-0.028	0.058*	0.028
2	0	-0.003	0.006	0.003
	0.1	0.039*	-0.006	-0.003
3	0	0.000	-0.000	0.053*
	0.1	0.031*	0.008	0.011

* Significant at P<0.05.

treated with sodium lactate and/or sodium diacetate behaved similar to the untreated samples irrespective of the duration of storage (Table 15). All the treatment groups comparisons were not significantly different from each other (Table 16). Basically, for all the treatments, the meat pieces were held together by the Fibrimex® without breaking apart when handled. Therefore, the data demonstrated that sodium lactate at 1.5% and 2.0% with or without 0.1% sodium diacetate could be used together with Fibrimex® binding system for the production of restructured turkey steaks. The Fibrimex® binding capability was not significantly affected by freezing the restructured turkey breasts for up to 3 months at -30°C.

Binding Strength

There was no interaction effect between treatment and month of storage for the binding strength of the restructured turkey steaks. The Fibrimex® binding capability was not significantly affected by freezing the product for up to 3 months at -30°C. Therefore, all the treatments behaved the same irrespective of the duration of storage. Steaks that did not receive any sodium lactate and/or sodium diacetate had significantly higher binding strength when compared with steaks treated with sodium lactate and/or sodium diacetate (Table 17). Steaks that were treated with

Table 15. Least square mean values[*] of binding scores[**] for restructured turkey steak made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Sodium diacetate level (%)	Sodium lactate level (%)		
	0	1.5	2.0
0	4.98a	4.99a	4.90a
0.1	4.88a	4.93a	4.97a

[*] Means bearing the same letter are not significantly different ($P>0.05$).

[**] Binding score: 1=100% break and 5=100% binding.

Table 16. P-values of comparisons for binding scores of steaks made with Fibrimex® and treated sodium lactate (NaL) and/or sodium diacetate (NaD).

Comparisons[a]	P-values[b]
5 vs 3,4	0.0573
1,2 vs 3,4	0.9248
6 vs 1,2	0.4212
5,6 vs 1,2,3,4	0.0721

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

Table 17. Least square mean values* of binding strength (kgf) of the restructured turkey steak made with Fibrimex® and treated sodium lactate and/or sodium diacetate.

Sodium diacetate level (%)	Sodium lactate level (%)		
	0	1.5	2.0
0	0.145b	0.105a	0.108a
0.1	0.115a	0.107a	0.114a

---

* Means bearing the same letter are not significantly different (P>0.05).

only sodium diacetate did not differ significantly when compared with steaks treated with either 1.5% or 2.0% sodium lactate. Similarly, steaks that were treated with only sodium diacetate did not differ significantly in the binding strength when compared with steaks from the treatment groups with the addition of both sodium lactate and sodium diacetate (Table 18). Besides, steaks from the treatment groups with the addition of only sodium lactate did not differ significantly when compared with steaks from the treatment groups that received both sodium lactate and sodium diacetate. The addition of sodium diacetate with the absence of sodium lactate resulted in significantly lower binding strength when compared with steaks from the treatment groups that were treated with sodium diacetate in the presence of sodium lactate (Table 18). The effect of adding sodium diacetate and/or sodium lactate on the binding strength of Fibrimex® has not been documented in the literature. However, with algin-calcium binding system, decreasing the pH reduced the binding strength (Johnson et al., 1990; Clarke et al., 1988). Muller et al. (1991) found that the addition of adipic acid to beef steakettes manufactured with algin-calcium binding system decreased the binding strength with freezing, however, the meat was still able to maintain its binding strength integrity.

Table 18. P-values of comparisons for the binding strength (kgf) of restructured turkey steaks made with Fibrimex® and treated sodium lactate and/or sodium diacetate.

Comparisons[a]	P-values[b]
5 vs 3,4	0.6155
1,2 vs 3,4	0.5308
6 vs 1,2	0.0001
5,6 vs 1,2,3,4	0.0319

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

Even though restructured turkey breasts when treated with sodium lactate and/or sodium diacetate and stored for 3 months at -30°C produced steaks that had lower binding strength when compared with control, the preservatives still have potential to be used with Fibrimex®. From the binding and binding integrity scores studies, the meat pieces were held together by Fibrimex® even in the presence of sodium lactate and/or sodium diacetate. Therefore, 1.5% and 2.0% sodium lactate, with or without 0.1% sodium diacetate could be used together with Fibrimex® for the production of steaks for retail meat from restructured turkey breasts. The binding strength of treated steaks were lower, yet the steaks could be displayed and handled without falling apart. Besides, from the microbiological analysis, further advantage could be obtained by incorporating Fibrimex® with sodium diacetate with or without sodium lactate whereby an extension in lag phase period of psychrotrophic growth and the shelf life of the product were observed. Therefore, the method used in this study could be utilized in production of restructured turkey steaks and broaden available purchasing selections for the consumers.

Objective Color Measurement for L* Value

The results obtained for the L* values are shown in Figure 9. The L* value is an indication of lightness (100 for perfect

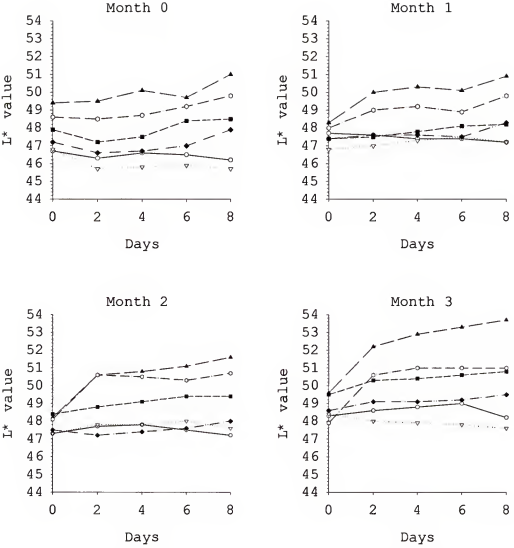

Figure 9. Mean L* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 month at -30°C.(—○— 1.5% NaL, ··▽·· 2.0% NaL,—■— 1.5% NaL + 0.1% NaD, —◆— 2.0% NaL + 0.1% NaD,—▲— 0.1% NaD,—○— Control).

white and 0 for black). At each storage month, steaks that were untreated and treated with either sodium diacetate or combination of sodium diacetate with sodium lactate showed very slight upward trend in the L* value (Table 19). Brewer et al. (1991) observed that fresh pork sausage stored at 4°C that and treated with 1, 2, or 3% sodium lactate increased in L* values when kept for 14 days, but decreased at day 17. In the present study, steaks that were treated with 1.5% sodium lactate showed very slight decrease in the L* values when sliced from restructured turkey breasts stored at -30°C for 0, 1, and 2 months, and steaks treated with 2.0% sodium lactate obtained from restructured turkey breasts stored at -30°C for 0 and 2 months. However, steaks treated with 2.0% sodium lactate showed very slight increase in the L* values when sliced from restructured turkey breasts stored at -30°C for 1 and 2 months (Table 19).

The mean values of different treatments and P-values for the comparisons for L* value at month 0, 1, 2, and 3 are shown in Table 20, Table 21, Table 22, and Table 23, respectively. At 0 month, the treatment groups with the addition of sodium lactate were found to have significantly lower L* values than the control from day 2 to 8 of storage (Table 20). A similar pattern was also observed at month 1 (Table 21) and 3 (Table 23) where steaks treated with sodium lactate had lower L* values when compared with

Table 19. Slope of L* values for steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	0.151*	-0.039	-0.091
	0.1	0.113	0.123*	0.091
1	0	0.077	-0.066	0.002
	0.1	0.233	0.167*	0.123*
2	0	0.249*	-0.022	0.040
	0.1	0.371*	0.131*	0.073
3	0	0.324*	0.002	-0.093
	0.1	0.456*	0.151*	0.095

* Significant at P<0.05.

Table 20. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	46.7	46.3	46.6	46.5	46.2
(2) 2.0% NaL	46.8	45.7	45.8	45.9	45.7
(3) 1.5% NaL + 0.1% NaD	47.9	47.2	47.5	48.4	48.5
(4) 2.0% NaL + 0.1% NaD	47.2	46.6	46.7	47.0	47.9
(5) 0.1% NaD	49.4	49.5	50.1	49.7	50.4
(6) Control	48.6	48.5	48.7	49.2	49.8
P-values					
(A) Treatment[a]	.1311	.0124	.0075	.0230	.0036
(B) Comparisons[b]					
1 vs 5	.0011	.0001	.0001	.0001	.0001
2 vs 5	.0013	.0001	.0001	.0001	.0001
5 vs 6	.3167	.1609	.0436	.4469	.3650
5 vs 3,4	.0081	.0001	.0001	.0016	.0006
1,2 vs 3,4	.1597	.0603	.0534	.0071	.0001
6 vs 1,2	.0082	.0001	.0001	.0001	.0001
5,6 vs 1,2,3,4	.1043	.0267	.0062	.0292	.0011

[a, b] Value significantly different if $P<0.05$.

Table 21. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	47.7	47.8	47.4	47.4	47.2
(2) 2.0% NaL	47.2	47.0	47.4	47.3	47.1
(3) 1.5% NaL + 0.1% NaD	47.7	48.1	48.7	48.8	49.1
(4) 2.0% NaL + 0.1% NaD	47.4	48.0	47.9	48.0	48.6
(5) 0.1% NaD	49.4	50.5	50.6	50.9	51.5
(6) Control	49.0	49.4	49.5	49.3	49.8
P-values					
(A) Treatment[a]	.0511	.0066	.0195	.0108	.0056
(B) Comparisons[b]					
1 vs 5	.0161	.0002	.0001	.0001	.0001
2 vs 5	.0024	.0001	.0001	.0001	.0001
5 vs 6	.5530	.1107	.1415	.0199	.0115
5 vs 3,4	.0028	.0001	.0003	.0001	.0001
1,2 vs 3,4	.8620	.1892	.0724	.0391	.0006
6 vs 1,2	.0132	.0011	.0006	.0011	.0001
5,6 vs 1,2,3,4	.5588	.0404	.0261	.0022	.0001

[a, b] Value significantly different if $P<0.05$.

Table 22. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	47.3	47.7	47.8	47.5	47.2
(2) 2.0% NaL	47.3	47.8	47.8	48.0	47.6
(3) 1.5% NaL + 0.1% NaD	48.4	48.8	49.1	49.4	49.4
(4) 2.0% NaL + 0.1% NaD	47.5	47.2	47.4	47.6	48.0
(5) 0.1% NaD	48.2	50.6	50.8	51.1	51.6
(6) Control	48.1	50.6	50.5	50.3	50.7
P-values					
(A) Treatment[a]	.7451	.0507	.0620	.0397	.0302
(B) Comparisons[b]					
1 vs 5	.1131	.0001	.0001	.0001	.0001
2 vs 5	.1289	.0001	.0001	.0001	.0001
5 vs 6	.8579	.9725	.5943	.2087	.1471
5 vs 3,4	.6218	.0001	.0001	.0001	.0001
1,2 vs 3,4	.1112	.4439	.2793	.0661	.0050
6 vs 1,2	.1129	.0001	.0001	.0001	.0001
5,6 vs 1,2,3,4	.2852	.6379	.2898	.0378	.0053

[a, b] Value significantly different if $P<0.05$.

Table 23. Mean for L* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	48.3	48.6	48.8	49.0	48.2
(2) 2.0% NaL	48.4	48.0	47.9	47.8	47.6
(3) 1.5% NaL + 0.1% NaD	49.5	50.3	50.4	50.6	50.8
(4) 2.0% NaL + 0.1% NaD	48.6	49.1	49.1	49.2	49.5
(5) 0.1% NaD	49.6	52.2	52.9	53.3	53.7
(6) Control	47.9	50.6	51.0	51.0	51.0
P-values					
(A) Treatment[a]	.3148	.0075	.0032	.0031	.0009
(B) Comparisons[b]					
1 vs 5	.0844	.0001	.0001	.0001	.0001
2 vs 5	.1073	.0001	.0001	.0001	.0001
5 vs 6	.0243	.0108	.0032	.0005	.0003
5 vs 3,4	.3729	.0001	.0001	.0001	.0001
1,2 vs 3,4	.2014	.0021	.0029	.0011	.0001
6 vs 1,2	.4870	.0001	.0001	.0001	.0001
5,6 vs 1,2,3,4	.0105	.0001	.0001	.0001	.0001

[a, b] Value significantly different if $P<0.05$.

control from day 2 to 8 of storage. However, when restructured turkey breasts were stored for 2 months at -30°C, no significant differences were observed for the L* values of the restructured steaks from day 0 to day 4 among the treatments (Table 22). Even though there were no significant differences from day 0 to day 4, the treatment groups with the addition of sodium lactate had lower L* values when compared with control. Beyond that storage period, similar observations as month 0, 1 and month 3 were observed for month 2 wherein the steaks treated with sodium lactate had significantly lower L* values when compared to untreated steaks. Papadopoulos et al. (1991c) also observed that cooked beef top rounds treated with sodium lactate were darker than untreated top rounds. A similar observation was reported where cooked, vacuum-packaged beef top rounds treated with 3.0% sodium lactate (Maca et al., 1997b) or 4.0% sodium lactate (Maca et al., 1999) had darker color when compared with the control. Raw meat has darker color with increased pH (Ockerman and Cahill, 1977; Forrest et al., 1975). Since sodium lactate cause treated samples to have higher pH, we would expect that the samples would be darker than untreated steaks.

At month 0, steaks treated with sodium diacetate alone did not differ significantly from the control except at day 4 where sodium diacetate treated steaks had higher L* values (Table 20).

However, at month 1, steaks treated with sodium diacetate did not show significant differences for L* values except at day 6 and day 8 (Table 21). Different results were obtained at month 2 where steaks treated with sodium diacetate did not differ significantly for the L* values when compared to the untreated steaks through 8 days storage ($P>0.05$). In contrast, at month 3, there were significant differences ($P<0.05$) between steaks treated with sodium diacetate and untreated steaks from day 2 to day 8. Even though the significant differences were not consistent over month of storage, steaks treated with sodium diacetate had higher L* values than untreated steaks except at day 2 for restructured turkey breasts stored for 2 month where both had similar L* value. When considering pH, sodium diacetate when added to meat would cause the pH of the meat to decrease. Therefore, it would be expected that meat and meat products treated with sodium diacetate would have higher L* values, thus look more pale in appearance. Forrest et al. (1975) stated that muscles with lower pH would be pale in color, and have very low water holding capacity, thus will give a cut surface of very wet appearance when compared with muscles with higher pH. Kotula and Thelappurate (1994) observed that beef rib steaks treated with acetic acid and lactic acid solutions had paler color than non treated control. Barbut (1993) also demonstrated that lighter color exhibited lower pH.

Steaks that came from restructured turkey breasts that were stored for 0 or 1 month at -30°C when treated with sodium diacetate without the presence of sodium lactate caused a more significant change in the L* value when compared to steaks treated with sodium diacetate in the presence of sodium lactate (Table 20 and Table 21). However, change in L* values at month 2 were only significant at day 6 and 8 of storage. Nevertheless, at 3 month storage, the significant changes in the amount of L* values were higher for steaks treated with sodium diacetate without the presence of sodium lactate than steaks treated with sodium diacetate in the presence of sodium lactate (Table 23).

From day 0 to day 4 for month 0 (Table 20) and month 1 (Table 21), steaks treated with sodium lactate alone did not differ significantly ($P>0.05$) from steaks treated with combination of sodium lactate and sodium diacetate. However, from day 6 to day 8, steaks treated with only sodium lactate had lower L* values than steaks treated with combination of sodium lactate and sodium diacetate ($P<0.05$). At month 2, steaks treated with sodium lactate alone when compared with steaks treated with combination of sodium lactate and sodium diacetate did not show any significant differences in the L* values except at day 8 (Table 22). With longer storage of the restructured turkey breasts (3 months), significant differences were observed from day 2 to day

8 when comparing steaks treated with sodium lactate alone with steaks treated with combination of sodium lactate and sodium diacetate (Table 23). Even though inconsistency in the distribution of the significant differences were observed through 8 days storage, steaks that were treated with combination of sodium lactate and sodium diacetate had higher L* values when compared with steaks treated with only sodium lactate.

From day 2 to day 8, steaks from restructured turkey breasts that were stored for 0 (Table 20), 1 (Table 21), and 3 month (Table 23) at -30°C and treated with sodium diacetate significantly showed higher L* values when compared to the steaks treated with both sodium lactate and sodium diacetate. However, at month 2, steaks treated with sodium diacetate had significantly higher L* values compared with steaks treated with both sodium lactate and sodium diacetate only at day 6 and day 8 of storage (Table 22). Nevertheless, in general, steaks when treated with sodium diacetate alone resulted in a higher L* value when compared with steaks treated with a combination of sodium lactate and sodium diacetate.

Sodium lactate when used in the steaks by itself resulted in a lower L* values when compared to steaks treated with sodium diacetate. From day 2 to day 8, steaks from restructured turkey breasts that were stored for 0 (Table 20), 1 (Table 21) and 3 month (Table 23) at -30°C, when treated with only sodium lactate significantly showed lower L* values when compared to the steaks treated with only sodium diacetate. However, significant difference were only observed from day 6 to day 8, where steaks with sodium lactate from restructured turkey breasts that were stored for 2 months at -30°C had significantly lower L* values when compared with steaks with sodium diacetate. Again, steaks when treated with only sodium diacetate resulted in a higher L* value, while steaks treated with only sodium lactate had lower L* value.

Objective Color Measurement for a* Value

The results obtained for the a* values at each storage time are shown in Figure 10. The a* value is an indication of redness, where positive value for red and negative for green. Restructured turkey breasts that were stored at -30°C for 0, 1, 2, and 3 months produced steaks with decreasing trend in the a* value through 8 days storage for all treatments (Table 24). Initially, at 0, 1, 2, and 3 months, the a* values for the steaks were in the range of 5.8 to 6.4, but at day 8 of storage, the a* values were in the range of 3.4 to 3.7. The decreased in the a* values over time of storage were almost similar among all treatments. Similarly, Boles and Shand (1999) observed that the redness of restructured

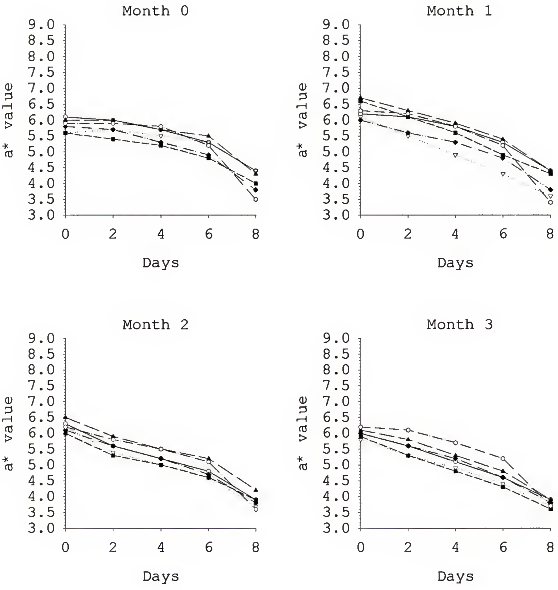

Figure 10. Mean a* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C.(—○— 1.5% NaL, ··▽·· 2.0% NaL,--■-- 1.5% NaL + 0.1% NaD, —◆-- 2.0% NaL + 0.1% NaD,—▲— 0.1% NaD,—◇— Control).

Table 24. Slope of a* values for turkey steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	-0.271*	-0.199*	-0.133*
	0.1	-0.168*	-0.195*	-0.243*
1	0	-0.309*	-0.235*	-0.301*
	0.1	-0.290*	-0.288*	-0.272*
2	0	-0.249*	-0.281*	-0.290*
	0.1	-0.269*	-0.247*	-0.275*
3	0	-0.295*	-0.248*	-0.254*
	0.1	-0.268*	-0.281*	-0.273*

* Significant at $P<0.05$.

beef made with Fibrimex® decreased with retail storage. Banks et al. (1998) observed that red color due to oxymyoglobin decreased with increasing sodium lactate concentration.

The mean a* value for different treatments at month 0, 1, 2, and 3 are shown in Table 25, Table 26, Table 27, and Table 28, respectively. Steaks from restructured turkey breasts that were stored for 0, 1, 2, and 3 months at -30°C when treated with sodium lactate did not differ significantly in the a* values when compared with untreated steaks at all storage conditions. McKeith et al. (1994) also observed that for boneless pork loin slice dipped in 3.0% sodium lactate solution the a* value was not significantly different from the untreated sample. Maca et al. (1997a) observed that vacuum-packaged ground beef patties when treated with 2.0 to 4.0% sodium lactate, 0.1% to 0.3% sodium citrate, or 0.1% to 0.3% sodium acetate, and stored for 28 days at 4°C , did not differ significantly in a* values from the untreated patties.

The a* values for steaks treated with 0.1% sodium diacetate did not differ significantly from untreated steaks (control) through 8 days storage except at month 1 where steaks on day 8 treated with sodium diacetate had higher a* value when compared with untreated steaks (Table 26). Zhuang et al. (1996) observed that catfish fillets treated with 2.0% sodium acetate did not

Table 25. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	6.1	5.9	5.7	5.3	4.4
(2) 2.0% NaL	5.6	5.7	5.5	5.3	4.4
(3) 1.5% NaL + 0.1% NaD	5.6	5.4	5.2	4.8	4.0
(4) 2.0% NaL + 0.1% NaD	5.8	5.7	5.3	4.9	3.8
(5) 0.1% NaD	6.0	6.0	5.7	5.5	4.6
(6) Control	5.9	5.9	5.8	5.2	3.6
P-values					
(A) Treatment[a]	.6621	.4095	.1465	.4730	.0654
(B) Comparisons[b]					
1 vs 5	.6846	.8657	.9665	.7210	.5706
2 vs 5	.1391	.2127	.5061	.7169	.5749
5 vs 6	.9725	.6899	.7281	.4789	.0010
5 vs 3,4	.3119	.0504	.0942	.0364	.0081
1,2 vs 3,4	.6334	.1590	.1067	.0394	.0138
6 vs 1,2	.5592	.7195	.4469	.6871	.0015
5,6 vs 1,2,3,4	.8046	.6233	.2237	.5332	.1888

[a, b] Value significantly different if $P<0.05$.

Table 26. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	6.2	5.9	5.7	5.3	4.2
(2) 2.0% NaL	6.0	5.5	4.9	4.4	3.5
(3) 1.5% NaL + 0.1% NaD	6.4	5.9	5.3	4.8	4.1
(4) 2.0% NaL + 0.1% NaD	6.1	5.6	5.3	4.7	3.9
(5) 0.1% NaD	6.5	6.1	5.7	5.1	4.1
(6) Control	6.0	6.0	5.6	5.0	3.4
P-values					
(A) Treatment[a]	.0974	.0815	.1017	.0324	.0386
(B) Comparisons[b]					
1 vs 5	.3119	.4919	.8977	.6075	.6848
2 vs 5	.0478	.0232	.0136	.0260	.0291
5 vs 6	.0471	.7450	.7260	.6988	.0150
5 vs 3,4	.3345	.1316	.1304	.1971	.5724
1,2 vs 3,4	.3454	.7976	.0000	.7227	.5598
6 vs 1,2	.5642	.1789	.2656	.5767	.0727
5,6 vs 1,2,3,4	.0310	.6792	.7747	.9115	.0203

[a, b] Value significantly different if P<0.05.

Table 27. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	6.3	5.6	5.2	4.8	3.9
(2) 2.0% NaL	6.2	5.4	5.0	4.6	3.7
(3) 1.5% NaL + 0.1% NaD	6.0	5.3	5.0	4.6	3.9
(4) 2.0% NaL + 0.1% NaD	6.1	5.6	5.2	4.7	3.8
(5) 0.1% NaD	6.5	5.9	5.5	5.2	4.2
(6) Control	6.2	5.8	5.5	5.1	3.6
P-values					
(A) Treatment[a]	.8027	.7087	.7133	.5881	.4240
(B) Comparisons[b]					
1 vs 5	.2935	.1547	.1570	.1529	.2080
2 vs 5	.1202	.0530	.0495	.0329	.0565
5 vs 6	.1221	.5955	.7997	.7649	.0193
5 vs 3,4	.0185	.0263	.0303	.0198	.1335
1,2 vs 3,4	.2831	.7158	.7816	.7259	.6842
6 vs 1,2	.7756	.1822	.0966	.0859	.3701
5,6 vs 1,2,3,4	.5171	.8231	.9624	.9667	.0319

[a], [b] Value significantly different if $P<0.05$.

Table 28. Mean for a* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	6.0	5.6	5.1	4.6	3.9
(2) 2.0% NaL	5.8	5.3	4.9	4.4	3.7
(3) 1.5% NaL + 0.1% NaD	5.9	5.3	4.8	4.3	3.6
(4) 2.0% NaL + 0.1% NaD	6.0	5.6	5.2	4.6	3.8
(5) 0.1% NaD	6.1	5.8	5.3	4.8	3.9
(6) Control	6.2	6.1	5.7	5.2	3.7
P-values					
(A) Treatment[a]	.7637	.1155	.0876	.0907	.5285
(B) Comparisons[b]					
1 vs 5	.5260	.4151	.3762	.4837	.9577
2 vs 5	.1773	.0540	.0797	.1065	.4101
5 vs 6	.9420	.2319	.1775	.2424	.4168
5 vs 3,4	.4805	.1001	.1372	.1353	.3333
1,2 vs 3,4	.5878	.9400	.9640	.8457	.5215
6 vs 1,2	.2193	.0036	.0025	.0081	.6220
5,6 vs 1,2,3,4	.7997	.3076	.2815	.2860	.7692

[a, b] Value significantly different if $P<0.05$.

differ significantly in the a* value when compared with untreated catfish fillets. At month 0, 1, 2, and 3, steaks treated with 0.1% sodium diacetate did not differ significantly in the a* values when compared with steaks treated with 1.5% sodium lactate through 8 days storage at 0°C. When sodium lactate level increased to 2.0%, there were no significant differences when compared with steaks treated with 0.1% sodium diacetate at all storage conditions except at day 6 and day 8 for steaks from restructured turkey breasts stored for 1 month (Table 26). In general, steaks treated with 0.1% sodium diacetate had slightly higher a* values than steaks treated with 2.0% sodium lactate at all storage conditions.

Comparisons between steaks treated with both sodium lactate and sodium diacetate, and with sodium diacetate alone did not differ significantly in the a* values at all storage conditions. Generally, at all storage conditions, steaks when treated with sodium diacetate resulted in slightly higher a* value when compared with steaks treated with combinations of sodium lactate and sodium diacetate. Regardless of the storage conditions, steaks when treated with sodium diacetate without the presence of sodium lactate did not significantly change in the a* value when compared to steaks treated with sodium diacetate in the presence of sodium lactate except on day 8 at 1 month storage (Table 26).

On day 8 at 1 month storage, the effect due to the addition of sodium diacetate in the absence of sodium lactate significantly increased the b* value when compared to steaks treated with sodium diacetate in the presence of sodium lactate (Table 26).

Objective Color Measurement for b* Value

The results obtained for the b* values at each storage time are shown in Figure 11. The b* value is an indication of yellowness, where positive value for yellow and negative for blue. At all storage periods, the steaks for all treatments showed increasing trend in the b* values (Table 29). Banks et al. (1998) observed that yellowness in pork loin containing 1.0 to 2.0% sodium lactate increased after 14 days of storage. Maca et al. (1997a) observed that raw ground beef patties became brighter, lighter, and more yellow with storage. In the present study, the increased in the b* values were found to be significant at all storage periods except at month 0 for steaks treated with 1.5% sodium lactate or 0.1% sodium diacetate. Even though most of the changes in slope were significant, but the amount of the change in the b* values for each increased in storage time were very small.

The mean values for different treatments and P-values for the treatments and comparisons for b* value at month 0, 1, 2, and

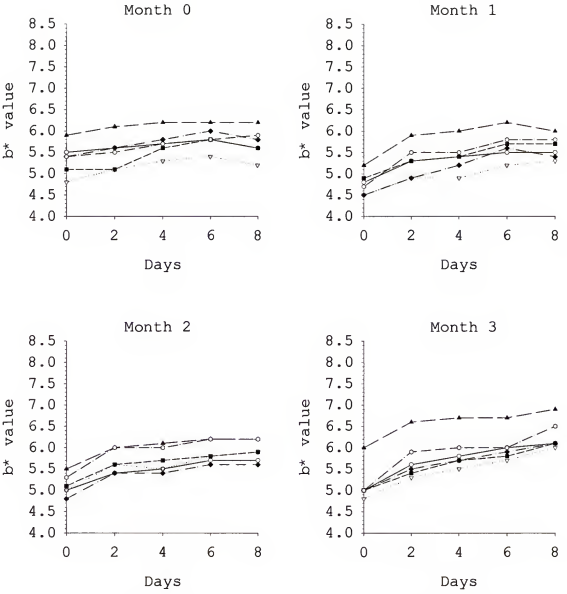

Figure 11. Mean b* values for turkey steaks stored for 8 days at 0°C made from restructured turkey breasts with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) stored at 0, 1, 2, and 3 months at -30°C.(—○— 1.5% NaL, ▿ 2.0% NaL,--■-- 1.5% NaL + 0.1% NaD, —◆-- 2.0% NaL + 0.1% NaD,—▲— 0.1% NaD,—○-- Control).

Table 29. Slope of b* values for turkey steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -32°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate and/or sodium diacetate.

Month	Sodium diacetate level (%)	Sodium lactate level (%)		
		0	1.5	2.0
0	0	0.069*	0.026	0.059*
	0.1	0.024	0.087*	0.064*
1	0	0.121*	0.081*	0.101*
	0.1	0.097*	0.103*	0.098*
2	0	0.099*	0.093*	0.100*
	0.1	0.075*	0.092*	0.096*
3	0	0.149*	0.124*	0.141*
	0.1	0.105*	0.126*	0.126*

* Significant at $P<0.05$.

3 are shown in Table 30, Table 31, Table 32, and Table 33, respectively. There were inconsistency in the distributions of the significant differences for the comparisons made among different treatment groups over storage time. Greater significant differences among the comparisons were observed for steaks from turkey breasts stored for 3 months (Table 33) than steaks from turkey breasts stored for 0 (Table 30) or 2 months (Table 32). However, no significant differences were observed among treatments for steaks obtained from restructured turkey breasts stored for 1 month at -30°C (Table 31).

Restructured turkey breasts stored for 0 and 1 month when treated with sodium lactate produced steaks that did not differ significantly in the b* value when compared with untreated steaks stored for 0, 2, 4, and 6 days (Table 30 and Table 31). However, when restructured turkey breasts were stored for 3 months, those treated with sodium lactate produced steaks that had significantly lower b* values when compared with untreated steaks stored on day 2 and 4 (Table 33). Similarly, at month 2, those treated with sodium lactate produced steaks that had significantly lower b* values when compared with untreated steaks stored on day 4 (Table 32). At month 0, significant difference was also observed for steaks treated with sodium lactate when compared untreated steaks at day 8 (Table 30). In general, at all storage conditions, the

Table 30. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 0 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	5.5	5.6	5.7	5.8	5.6
(2) 2.0% NaL	4.8	5.1	5.3	5.4	5.2
(3) 1.5% NaL + 0.1% NaD	5.1	5.1	5.6	5.8	5.6
(4) 2.0% NaL + 0.1% NaD	5.4	5.6	5.8	6.0	5.8
(5) 0.1% NaD	5.9	6.1	6.2	6.2	6.1
(6) Control	5.4	5.5	5.7	5.8	5.9
P-values					
(A) Treatment[a]	.0656	.0629	.1040	.0447	.0378
(B) Comparisons[b]					
1 vs 5	.0426	.0070	.0177	.0449	.0163
2 vs 5	.0001	.0001	.0001	.0001	.0001
5 vs 6	.0237	.0031	.0046	.0724	.3855
5 vs 3,4	.0005	.0001	.0043	.0764	.0287
1,2 vs 3,4	.4930	.7549	.0858	.0293	.0404
6 vs 1,2	.1353	.2649	.3224	.1368	.0045
5,6 vs 1,2,3,4	.0252	.0092	.0011	.0069	.0589

[a, b] Value significantly different if $P<0.05$.

Table 31. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 1 month) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	5.1	5.5	5.7	5.8	5.7
(2) 2.0% NaL	4.8	5.1	5.3	5.5	5.6
(3) 1.5% NaL + 0.1% NaD	5.2	5.6	5.7	6.0	6.0
(4) 2.0% NaL + 0.1% NaD	4.9	5.1	5.5	5.7	5.6
(5) 0.1% NaD	5.5	6.0	6.2	6.4	6.2
(6) Control	4.8	5.6	5.6	5.9	5.9
P-values					
(A) Treatment[a]	.2339	.0806	.0894	.0878	.1794
(B) Comparisons[b]					
1 vs 5	.1481	.0174	.0720	.0126	.0599
2 vs 5	.0106	.0001	.0001	.0007	.0137
5 vs 6	.0152	.0717	.0278	.0427	.1886
5 vs 3,4	.0539	.0019	.0071	.0084	.0614
1,2 vs 3,4	.6287	.5376	.7351	.3311	.4230
6 vs 1,2	.6130	.1155	.6771	.2673	.3100
5,6 vs 1,2,3,4	.0237	.0683	.0461	.0273	.1255

[a, b] Value significantly different if P<0.05.

Table 32. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 2 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	5.0	5.4	5.5	5.7	5.7
(2) 2.0% NaL	5.0	5.6	5.5	5.8	5.9
(3) 1.5% NaL + 0.1% NaD	5.1	5.6	5.7	5.8	5.9
(4) 2.0% NaL + 0.1% NaD	4.8	5.4	5.4	5.6	5.6
(5) 0.1% NaD	5.5	6.0	6.1	6.2	6.2
(6) Control	5.3	6.0	6.0	6.2	6.2
P-values					
(A) Treatment[a]	.0292	.0515	.0356	.1010	.2290
(B) Comparisons[b]					
1 vs 5	.0213	.0040	.0111	.0478	.0982
2 vs 5	.0231	.0319	.0280	.1108	.2141
5 vs 6	.3178	.7489	.6734	.8897	.9500
5 vs 3,4	.0046	.0047	.0122	.0235	.0660
1,2 vs 3,4	.7896	.9366	.7783	.7925	.8322
6 vs 1,2	.1305	.0111	.0238	.0571	.1099
5,6 vs 1,2,3,4	.5074	.7587	.6125	.9691	.9433

[a, b] Value significantly different if $P<0.05$.

Table 33. Mean for b* values of steaks (stored at 0°C for 8 days) sliced from restructured turkey breasts (stored at -30°C for 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Day of storage				
	0	2	4	6	8
Treatments					
(1) 1.5% NaL	5.0	5.6	5.8	6.0	6.1
(2) 2.0% NaL	4.8	5.3	5.5	5.7	6.0
(3) 1.5% NaL + 0.1% NaD	5.0	5.4	5.7	5.8	6.1
(4) 2.0% NaL + 0.1% NaD	5.0	5.5	5.7	5.9	6.1
(5) 0.1% NaD	6.0	6.6	6.7	6.7	6.9
(6) Control	5.0	5.9	6.0	6.0	6.5
P-values					
(A) Treatment[a]	.0073	.0071	.0060	.0298	.0689
(B) Comparisons[b]					
1 vs 5	.0001	.0001	.0001	.0002	.0001
2 vs 5	.0001	.0001	.0001	.0001	.0001
5 vs 6	.0001	.0004	.0006	.0010	.0226
5 vs 3,4	.0001	.0001	.0001	.0001	.0001
1,2 vs 3,4	.4556	.9828	.7601	.9570	.7789
6 vs 1,2	.4653	.0035	.0212	.2093	.0198
5,6 vs 1,2,3,4	.0001	.0039	.0027	.0060	.0426

[a, b] Value significantly different if $P<0.05$.

treatment groups with addition of sodium lactate were found to have slightly lower b* values when compared to untreated steaks.

Restructured turkey breasts stored for 1 months at -30°C when treated with 0.1% sodium diacetate produced steaks that did not differ significantly in the b* values when compared with steaks treated with 1.5% sodium lactate through 8 days storage at 0°C (Table 31). However, at other storage periods, some significant differences were observed. At month 0, steaks treated with 0.1% sodium diacetate were significant difference when compared with steaks treated with 1.5% sodium lactate at day 6 and 8 (Table 30). However, at month 2, significant differences were observed only on day 0 and 4 for steaks treated with 0.1% sodium diacetate when compared with steaks treated with 1.5% sodium lactate (Table 32). Restructured turkey breasts stored for 3 months treated with sodium diacetate produced steaks that had significantly higher b* values on day 0, 2, 4, and 6 when compared with steaks treated with 1.5% sodium lactate (Table 33). Even though the distributions of the significant differences were inconsistent with storage time, steaks treated with 0.1% sodium diacetate always displayed slightly higher b* values compared with steaks treated with 1.5% or 2.0% sodium lactate at all storage conditions. At higher level of sodium lactate, similar results were obtained. Generally, steaks treated with sodium lactate had lower b* values when compared with steaks treated with 0.1% sodium diacetate at all storage periods.

Steaks treated with 0.1% sodium diacetate generally had higher b* values when compared with untreated steaks. Significant changes were only observed for restructured turkey breasts stored for 3 months and treated with 0.1% sodium diacetate produced steaks that had higher b* values on day 0, 2, 4, and 6 compared with untreated steaks. As with other comparisons with sodium diacetate, under all storage periods, generally, steaks treated with only 0.1% sodium diacetate had slightly higher b* values when compared with untreated steaks. Similarly, at all storage periods, steaks from the treatment groups with the addition of both sodium diacetate and sodium lactate had slight increased in the b* values when compared with steaks from treatment groups with the addition of only sodium lactate. However, the increased in the b* values caused by the addition of both sodium diacetate and sodium lactate were not significantly different except for steaks on day 6 and 8 that were obtained from restructured turkey breasts stored for 0 month when compared with steaks treated with only sodium lactate (Table 30). The amount of changed in the b* values brought about by addition of sodium diacetate with the absence of sodium lactate compared with steaks that had sodium lactate did not differ significantly except for steaks on day 0, 2, and 4 that were obtained from restructured turkey breasts stored for 3 months (Table 33), and on day 6 for steaks from restructured turkey breasts stored for 0 (Table 30) and 3 months (Table 33).

Even though there were some statistical significant differences in the b* values at different storage time for some comparisons, the differences among the treatments at each day (0, 2, 4, 6, and 8) were very small and could be considered as practically not significant. Such small differences were detectable by objective method for color measurement, but for the consumers, such differences would most likely goes unnoticed.

Thaw Loss

The thaw loss for steaks in all treatments (sliced from restructured turkey breasts stored for 0, 1, 2, and 3 months) are shown in Figure 12. At the beginning of the initial month of storage (month 0), there were no significant differences among all treatments. At each storage period, steaks treated with 0.1% sodium diacetate had the highest percentage for thaw loss (Figure 12). Mendonca et al. (1989) reported that fresh pork chops treated with lactic and acetic acids had an increased purge loss. Lower intracellular pH of meat caused shrinkage of meat myofibrils, thus causing drip loss (Offer and Trinick, 1983).

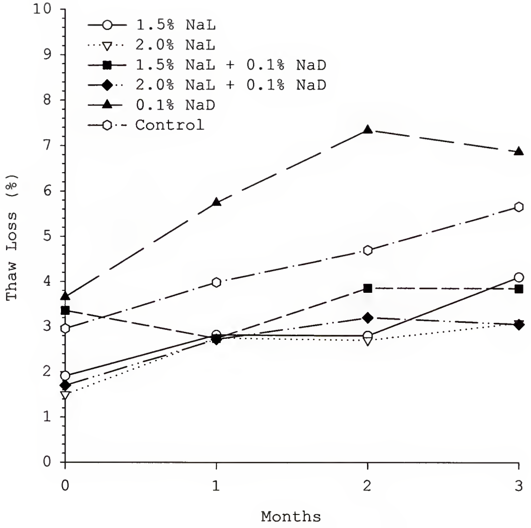

Figure 12. Mean of thaw loss for restructured turkey meat made with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD), stored at -30°C for a period of 0,1, 2, and 3 months.

After the initial storage, a significant increase in percentage of thaw loss for steaks treated with only sodium diacetate was observed when compared with steaks treated with either 1.5% or 2.0% sodium lactate (Table 34). At month 1 and 2, steaks that were treated with 0.1% sodium diacetate differ significantly when compared with steaks that were not treated (control) where the former had higher percentage of thaw loss. Therefore, generally, 0.1% sodium diacetate would result in greater percentage of thaw loss from the steaks. Sodium diacetate resulted in an increase in the percentage of thaw loss, but when used in combination with sodium lactate, the percentage of thaw loss decreased when compared with steaks treated with only sodium diacetate (Figure 12). The decrease in the percentage of thaw loss by addition of both sodium diacetate and sodium lactate differ significantly after month 0 when compared with steaks treated with only sodium diacetate (Table 34). However, treatment groups with the addition of both sodium diacetate and sodium lactate did not differ significantly in the percentage of thaw loss when compared with steaks from the treatment groups with the addition of only sodium lactate (Table 34). After month 0, steaks from the treatment groups with the addition of sodium lactate differ significantly when compared with the control (Table 34). Therefore, percentage of thaw loss in treated steaks were

Table 34. Mean for thaw loss of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Descriptions	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	1.91	2.82	2.80	4.09
(2) 2.0% NaL	1.50	2.75	2.70	3.08
(3) 1.5% NaL + 0.1% NaD	3.36	2.74	3.85	3.84
(4) 2.0% NaL + 0.1% NaD	1.70	2.72	3.20	3.05
(5) 0.1% NaD	3.66	5.74	7.34	6.86
(6) Control	2.96	3.98	4.69	5.65
P-values				
(A) Treatment[a]	0.2522	0.0021	0.0053	0.0164
(B) Comparisons[b]				
1 vs 5	0.1237	0.0006	0.0007	0.0190
2 vs 5	0.0640	0.0005	0.0006	0.0031
5 vs 6	0.5211	0.0165	0.0226	0.2584
5 vs 3,4	0.2409	0.0001	0.0009	0.0023
1,2 vs 3,4	0.2922	0.9068	0.3019	0.8537
6 vs 1,2	0.1957	0.0486	0.0470	0.0384
5,6 vs 1,2,3,4	0.2625	0.0477	0.0174	0.4067

[a, b] Value significantly different if $P<0.05$.

minimized with addition of sodium lactate. No study has been documented on the effect of sodium lactate on thaw loss. However, sodium lactate has been observed to suppress water activity (Chen and Shelef, 1992; De Wit and Rombouts, 1990; Anonymous, 1988; Duxbury, 1988; Chirife and Fontan, 1980). Meat with sodium lactate had higher pH than non treated meat (Houtsma et al., 1996). Sodium lactate has high pH between 5.7 to 8.5 (Grau, 1980). Forrest et al. (1975) stated that meat with high pH will tend to be dark in color, and very dry on the exposed cut surface due to the tightly bound water to the meat proteins. At high pH, muscle fibers are more tightly packed together as a result of increased water-holding capacity of muscle protein (Renerre, 1990).

Cooking Yield

The cooking yields for steaks in all treatments sliced from restructured turkey breasts (stored for 0, 1, 2, and 3 months at -30°C) are shown in Figure 13. Even though steaks that were treated with sodium lactate had higher cooking yield when compared with steaks that were not treated (control), the difference between them was not significant (Table 35). Sodium lactate when added to beef top rounds increased cooking yields (Papadopoulos et al., 1991a; Papadopoulos et al., 1991c). Williams et al.

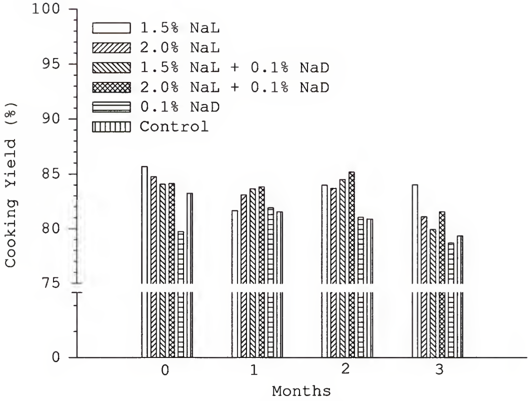

Figure 13. Mean cooking yield values for restructured turkey meat made with Fibrimex, and treated with sodium lactate (NaL) and/or sodium diacetate (NaD), stored at -30°C for a period of 0,1, 2, and 3 months.

Table 35. Mean for cooking yield of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Descriptions	Month of storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	85.67	81.65	83.98	84.01
(2) 2.0% NaL	84.76	83.09	83.68	81.09
(3) 1.5% NaL + 0.1% NaD	84.07	83.63	84.50	79.94
(4) 2.0% NaL + 0.1% NaD	84.12	83.82	85.18	81.55
(5) 0.1% NaD	79.73	81.92	81.05	78.70
(6) Control	83.23	81.55	80.89	79.34
P-values				
(A) Treatment[a]	0.3168	0.6930	0.2927	0.3044
(B) Comparisons[b]				
1 vs 5	0.0369	0.8869	0.2008	0.0403
2 vs 5	0.0699	0.5386	0.2471	0.3219
5 vs 6	0.1917	0.8469	0.9448	0.7835
5 vs 3,4	0.0694	0.2824	0.0660	0.3275
1,2 vs 3,4	0.5438	0.3217	0.5223	0.2906
6 vs 1,2	0.3823	0.6197	0.1434	0.1358
5,6 vs 1,2,3,4	0.1620	0.4632	0.6690	0.4026

[a, b] Value significantly different if $P<0.05$.

(1995) observed that fresh speckled bullhead catfish fillets when treated with either 0, 1 or 2% sodium lactate solutions (w/w) adjusted to pH 5.50 had higher cooking yield than the control. In this study, similarly, steaks treated with combination of sodium lactate with sodium diacetate had higher cooking yield, but when compared with steaks that were not treated, the difference between them were not significant (Table 35). Williams and Phillips (1998) observed that broiler breast meat treated with pH 7.30 and 5.50 sodium lactate solutions resulted in significantly higher cooking yields after 3 and 7 days of storage, when compared to control breast meat. Also, steaks that were treated with sodium diacetate did not differ significantly in the cooking yield when compared with untreated steaks (Table 35). The treatment groups for steaks with the addition of both sodium lactate and sodium diacetate did not differ significantly in the cooking yield when compared with steaks that were treated with sodium diacetate (Table 35). Similarly, the treatment groups for steaks that were treated with sodium lactate did not differ significantly in the cooking yield when compared with steaks from treatment groups with the addition of both sodium lactate and sodium diacetate (Table 35). Therefore, the levels of sodium diacetate, sodium lactate, or combination of both sodium lactate and sodium diacetate used in this study could be used with Fibrimex® for production of steaks from restructured turkey breasts even when stored at -30°C for 3 months without significantly affecting the cooking yield of the product.

2-Thiobarbituric Acid Test

There was no interaction effect between treatment and month of storage for the 2-Thiobarbituric Acid (TBA) values for steaks from restructured turkey breasts stored up to 3 months at -30°C. Restructured turkey breasts with the addition of either sodium diacetate, sodium lactate, or combination of sodium lactate and sodium diacetate produced steaks that had significantly higher TBA values when compared with steaks that were not treated (control) (Table 36). Rhee et al. (1998) observed that aerobically stored ground beef at 4°C when mixed with 3.0% sodium lactate had higher TBA value than untreated sample. Krahl et al. (1995) reported that sodium lactate acted as a prooxidant. Similarly, Kulshrestha and Rhee, 1996) reported that lactate had a prooxidative effect in aerobically-packaged beef patties stored at 4°C. Chow et al. (1996) observed that chicken breast treated with 2.0% lactic acid solution had higher TBA values compared to untreated sample. Steaks in the present study from treatment groups with the addition of both sodium diacetate and sodium lactate had significantly higher TBA value when compared with steaks from

Table 36. Least square mean for 2-Thiobarbituric Acid values* (mg malonaldehyde/kg) of steaks made with Fibrimex®, and treated with sodium lactate and/or sodium diacetate.

Sodium diacetate level (%)	Sodium lactate level (%)		
	0	1.5	2.0
0	0.34b	0.52ad	0.53ad
0.1	0.55d	0.66c	0.64c

* Means bearing the same letter are not significantly different (P>0.05).

treatment groups with the addition of only sodium lactate (Table 37). Similarly, steak treated with only sodium diacetate had significantly lower TBA value when compared with steak from treatment groups with the addition of both sodium lactate and sodium diacetate (Table 37). The addition of 0.1% sodium diacetate to steaks in the presence of sodium lactate resulted in significant increased in the TBA values when compared with addition of sodium diacetate to steaks in the absence of sodium lactate (Table 37). Reddy and Reddy (1994) observed that cockerel meat when treated with 0.5% acetic acid had significant increase in the TBA values. Even though in this study the treated steaks had significantly higher TBA values when compared with control, the TBA values were still very low.

Proximate Composition

The proximate compositions determined for each treatment for ash, moisture, protein, and ash are shown in Table 38. There were significant differences among treatments for ash content. Restructured turkey steaks treated with sodium lactate produced steaks that had significantly higher ash content when compared with steaks that were left untreated (control) or treated with sodium diacetate. Williams et al. (1995) also documented that sodium lactate treatments on fresh catfish fillets resulted in

Table 37. P-values of comparisons for 2-Thiobarbituric Acid values of steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Comparisons[a]	P-values[b]
5 vs 3,4	0.0295
1,2 vs 3,4	0.0013
6 vs 1,2	0.0001
5,6 vs 1,2,3,4	0.0001

[a] 1=1.5% NaL, 2=2.0% NaL, 3=1.5% NaL + 0.1% NaD, 4=2.0% NaL + 0.1% NaD, 5=0.1% NaD, 6=Control.

[b] Value significantly different if $P<0.05$.

Table 38. Mean proximate composition for steaks made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Ash	Moisture	Protein	Fat
Treatments				
(1) 1.5% NaL	1.44	74.70	22.10	0.75
(2) 2.0% NaL	1.58	74.13	22.91	0.82
(3) 1.5% NaL + 0.1% NaD	1.65	74.35	22.22	1.14
(4) 2.0% NaL + 0.1% NaD	1.76	74.01	23.26	0.94
(5) 0.1% NaD	1.07	74.89	22.70	0.93
(6) Control	1.08	74.46	23.37	1.13
P-values				
(A) Treatment[a]	0.0001	0.0863	0.0731	0.3580
(B) Comparisons[b]				
1 vs 5	0.0001	0.5460	0.2300	0.3822
2 vs 5	0.0001	0.0241	0.6752	0.5676
5 vs 6	0.7976	0.1901	0.1827	0.3698
5 vs 3,4	0.0001	0.0159	0.9259	0.5689
1,2 vs 3,4	0.0001	0.3171	0.5004	0.0919
6 vs 1,2	0.0001	0.8612	0.0504	0.0675
5,6 vs 1,2,3,4	0.0005	0.6158	0.4771	0.7952

[a, b] Value significantly different if $P<0.05$.

increased ash content. In this study, increasing the level of sodium lactate resulted in an increase in the ash content of the product. Bloukas et al. (1997) also observed that increasing the sodium lactate level significantly increased the ash content of frankfurters. The treatment groups for steaks with addition of sodium lactate had higher ash content when compared with steaks from the control group. Increasing the level of sodium lactate increased the ash content. The treatment groups for steaks treated with both sodium lactate and sodium diacetate had higher ash content when compared with the treatment groups for steaks treated with only sodium lactate.

All other comparisons for moisture, protein, and fat were not significantly different among the treatments (Table 38). Papadopoulos et al. (1991c) observed that fat and moisture content of cooked beef top rounds were not affected by addition of sodium lactate. Williams et al (1995) showed almost similar values for moisture and fat content for fresh catfish fillets treated with 1.0% or 2.0% sodium lactate when compared to control. Therefore, based on this study, sodium lactate and/or sodium diacetate could be used in restructured turkey breasts for production of restructured steaks for retail meat without affecting the moisture, protein, and fat content of the product.

Sensory Evaluations

For each treatment, the flavor intensity did not change much with increasing length of storage (Table 39). Steaks from the treatment groups with the addition of sodium lactate did not differ significantly in the flavor intensity when compared with the untreated steaks (control) at all storage periods (Table 39). Bloukas et al. (1997) did not observe significant differences in flavor intensity for frankfurters treated with either 1.0%, 2.0% or 3.0% sodium lactate when compared to control. The addition of sodium diacetate with the absence of sodium lactate did not differ significantly in the flavor intensity when compared to the treatment groups with the addition of sodium diacetate in the presence of sodium lactate (Table 39). Similar findings were observed for comparison between 0.1% sodium diacetate with 1.5% sodium lactate. Restructured turkey breasts that were treated with 0.1% sodium diacetate produced steaks that did not differ significantly in the flavor intensity at all storage periods (0, 1, 2, and 3 months) when compared with steaks treated with 1.5% sodium lactate. When sodium lactate level was increased to 2.0%, the flavor intensity of the steaks did not differ significantly when compared with steaks treated with 0.1% sodium diacetate except on month 2 where the former had slightly intense flavor than the latter steaks (Table 39). Similarly, at 0, 1, and 3

Table 39. Mean values for flavor intensity scores[a] of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	5.6	5.2	5.4	5.4
(2) 2.0% NaL	5.9	5.6	5.7	5.2
(3) 1.5% NaL + 0.1% NaD	5.6	5.4	6.0	5.7
(4) 2.0% NaL + 0.1% NaD	5.5	5.2	5.2	5.3
(5) 0.1% NaD	5.5	5.8	5.0	5.7
(6) Control	6.1	5.7	5.7	5.2
P-values				
(A) Treatment[b]	0.3730	0.1640	0.0111	0.3674
(B) Comparisons[c]				
1 vs 5	0.7853	0.0476	0.1494	0.3938
2 vs 5	0.2216	0.4255	0.0150	0.1447
5 vs 6	0.0784	0.7903	0.0219	0.1144
5 vs 3,4	0.8750	0.0396	0.0132	0.5265
1,2 vs 3,4	0.3867	0.5729	0.7588	0.3890
6 vs 1,2	0.2394	0.1932	0.6761	0.6222
5,6 vs 1,2,3,4	0.0533	0.9135	0.0883	0.0746

[a] Based on a 8-point scale (8=extremely intense, 1=extremely bland).

[b, c] Value significantly different if $P<0.05$.

months, steaks from the treatment groups with the addition of both sodium lactate and sodium diacetate did not differ significantly in the flavor intensity when compared to steaks treated with only sodium diacetate. However, at month 2, steaks from the treatment groups with the addition of both sodium lactate and sodium diacetate had slightly higher intense flavor when compared to steaks treated with only sodium diacetate (Table 39). Restructured turkey breast kept for 0, 1, and 3 months at -30°C when treated with 0.1% sodium diacetate produced steaks that did not differ significantly in the flavor intensity when compared with steaks that were not treated (Table 39). Only for restructured turkey breasts that were kept for 2 months at -30°C when treated with 0.1% sodium diacetate produced steaks that had significantly lower flavor intensity than untreated steaks (Table 39).

At all storage periods, there were no significant differences for juiciness for steaks treated with sodium diacetate when compared to control (Table 40). Similarly, steaks from the treatment groups with the addition of both sodium diacetate and sodium lactate did not differ significantly in juiciness when compared to control (Table 40). The levels of sodium lactate, sodium diacetate, or combination of sodium lactate and sodium diacetate used in this study could be used in the restructured

Table 40. Mean values for juiceness scores[a] of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD).

Description	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	5.7	4.9	5.2	5.0
(2) 2.0% NaL	5.5	5.2	5.4	5.0
(3) 1.5% NaL + 0.1% NaD	5.4	5.2	5.3	5.2
(4) 2.0% NaL + 0.1% NaD	5.1	4.5	5.1	4.9
(5) 0.1% NaD	5.2	5.4	4.5	5.0
(6) Control	5.8	4.9	5.0	4.9
P-values				
(A) Treatment[b]	0.3005	0.1001	0.0980	0.9713
(B) Comparisons[c]				
1 vs 5	0.1490	0.1069	0.0301	0.7984
2 vs 5	0.4299	0.4552	0.0053	1.0000
5 vs 6	0.1157	0.1069	0.0960	0.8984
5 vs 3,4	0.9394	0.0537	0.0186	0.7680
1,2 vs 3,4	0.1378	0.4813	0.5243	0.8567
6 vs 1,2	0.5947	0.6147	0.3348	0.7680
5,6 vs 1,2,3,4	0.0330	0.3606	0.0846	0.8348

[a] Based on a 8-point scale (8=extremely juicy, 1=extremely dry).

[b, c] Value significantly different if $P<0.05$.

turkey breasts without seriously affecting the juiciness of the product. Maca et al. (1997b) observed that cooked, vacuum-packaged beef top rounds when treated with 3.0% sodium lactate did not affect the juiciness of the product. Similarly, Bloukas et al. (1997) observed no significant different in juiciness for frankfurters treated with 1.0%, 2.0%, and 3.0% sodium lactate when compared to control. In contrast, Papadopoulos et al. (1991c) found that beef roasts treated with 1.0 to 4.0% sodium lactate were juicier than control roasts. Difference in the method of applying sodium lactate to the meat among these studies could probably result in the different outcome for juiciness.

From this study, there were some differences in the results among the three trials (replicates) for off-flavor scores throughout the storage periods (0, 1, 2, and 3 months). Due to this reason, the data were presented based on individual trials (Table 41) (Table 42) (Table 43). For all the trials, restructured turkey breasts when treated with 0.1% sodium diacetate produced steaks that did not differ significantly for the off-flavor scores when compared with steaks treated with 1.5% sodium lactate at all storage period. Similar findings were observed between steaks treated with 0.1% sodium diacetate and steaks that were untreated. Therefore, restructured turkey breasts when treated with either 0.1% sodium diacetate or 1.5% sodium lactate did not affect the

Table 41. Mean values for off-flavor scores[a] of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 1.

Description	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	4.4	5.8	5.6	5.4
(2) 2.0% NaL	4.3	4.8	4.4	4.3
(3) 1.5% NaL + 0.1% NaD	4.6	4.9	4.4	4.7
(4) 2.0% NaL + 0.1% NaD	4.4	4.1	4.4	4.9
(5) 0.1% NaD	5.2	5.3	5.3	5.7
(6) Control	5.7	5.9	5.9	6.0
P-values				
(A) Treatment[b]	0.1219	0.0118	0.0039	0.0061
(B) Comparisons[c]				
1 vs 5	0.1728	0.3294	0.6315	0.6364
2 vs 5	0.1203	0.3294	0.0594	0.0063
5 vs 6	0.4329	0.2242	0.2334	0.4788
5 vs 3,4	0.1444	0.0948	0.0305	0.0328
1,2 vs 3,4	0.7810	0.0424	0.0944	0.7380
6 vs 1,2	0.0116	0.1617	0.0305	0.0084
5,6 vs 1,2,3,4	0.6304	0.0322	0.0545	0.4410

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[a] Based on a 8-point scale (6=none detected, 1=extreme off-flavor).

[b, c] Value significantly different if P<0.05.

Table 42. Mean values for off-flavor scores[a] of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 2.

Description	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	4.7	5.6	5.0	5.6
(2) 2.0% NaL	4.8	4.4	5.6	4.8
(3) 1.5% NaL + 0.1% NaD	4.5	5.0	4.7	5.5
(4) 2.0% NaL + 0.1% NaD	3.8	4.4	5.0	4.5
(5) 0.1% NaD	5.8	5.4	5.4	5.6
(6) Control	5.3	5.7	5.7	5.8
P-values				
(A) Treatment[b]	0.0434	0.0037	0.4300	0.0181
(B) Comparisons[c]				
1 vs 5	0.0623	0.6288	0.4420	0.7772
2 vs 5	0.1074	0.0184	0.7970	0.0279
5 vs 6	0.4131	0.4690	0.6074	1.0000
5 vs 3,4	0.0033	0.0546	0.2391	0.0551
1,2 vs 3,4	0.1811	0.3070	0.2788	0.5491
6 vs 1,2	0.2724	0.0546	0.3753	0.1464
5,6 vs 1,2,3,4	0.9108	0.2390	0.2971	0.7290

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[a] Based on a 8-point scale (6=none detected, 1=extreme off-flavor).

[b, c] Value significantly different if $P<0.05$.

Table 43. Mean values for off-flavor scores[a] of steaks sliced from restructured turkey breasts (stored at -30°C for 0, 1, 2, and 3 months) made with Fibrimex® and treated with sodium lactate (NaL) and/or sodium diacetate (NaD) for trial 3.

Description	Month of Storage			
	0	1	2	3
Treatments				
(1) 1.5% NaL	4.6	4.9	5.1	4.6
(2) 2.0% NaL	3.6	4.1	4.4	4.6
(3) 1.5% NaL + 0.1% NaD	4.3	4.3	4.9	4.6
(4) 2.0% NaL + 0.1% NaD	4.6	3.4	5.4	4.3
(5) 0.1% NaD	5.1	5.1	5.4	5.5
(6) Control	5.4	5.6	5.6	5.5
P-values				
(A) Treatment[b]	0.0172	0.0407	0.1704	0.1228
(B) Comparisons[c]				
1 vs 5	0.3223	0.6747	0.5523	0.1131
2 vs 5	0.0045	0.1472	0.0428	0.1131
5 vs 6	0.6192	0.5296	0.7659	1.0000
5 vs 3,4	0.1193	0.0344	0.4929	0.0285
1,2 vs 3,4	0.3811	0.1865	0.2959	0.6264
6 vs 1,2	0.0061	0.0752	0.0648	0.0687
5,6 vs 1,2,3,4	0.9191	0.2033	0.7155	0.7785

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[a] Based on a 8-point scale (6=none detected, 1=extreme off-flavor).

[b, c] Value significantly different if $P<0.05$.

off-flavor of the product. However, inconsistent findings were observed among the trials when the level of sodium lactate increased. Nevertheless, in general, restructured turkey breasts when treated with 0.1% sodium diacetate produced steaks that had higher off-flavor scores, thus less off-flavor when compared with steaks treated with 2.0% sodium lactate. Inconsistent findings were also observed between steaks that were treated with only sodium diacetate and steaks that were treated with combination of sodium lactate and sodium diacetate. Even though 0.1% sodium diacetate when used alone resulted in higher off-flavor scores, when used together with sodium lactate did not seem to cause much increase the off-flavor scores. Based on the results obtained from all the trials, restructured turkey breasts in the presence of sodium lactate and sodium diacetate produced steaks with lower off-flavor scores than untreated steaks, thus stronger off-flavor when compared with untreated steaks.

Sodium lactate had been associated with flavor notes such as metallic, bitter, chemical, medicinal, sour, astringent, sodium, and salty (Maca et al., 1997; Williams et al., 1995; Papadopoulos et al, 1991a; Papadopoulos et al., 1991c). Higher percentage of detectable flavor notes associated with sodium lactate were noted by the panelists as the level of sodium lactate increased. The percentage of detectable flavor notes for steaks treated with 1.5%

and 2.0% sodium lactate were 34.38% and 53.13%, respectively. When the steaks were treated with combination of 0.1% sodium diacetate with either 1.5% or 2.0% sodium lactate, the detectable flavor notes were 54.17% and 51.04%, respectively. Nevertheless, steaks treated with only 0.1% sodium diacetate or not treated (control) had lower percentage of detectable flavor notes, 14.58% and 5.21%, respectively. Williams et al. (1995) documented that almost 60% of the panelist preferred the flavor imparted by the sodium lactate where the sodium lactate treated fresh catfish fillets had more flavor.

SUMMARY AND CONCLUSION

When 1.5% sodium lactate was added together with Fibrimex®, there was a significant ($P<0.05$) decrease in the total psychrotrophic counts from day 4 to day 6, but again it showed a similar growth pattern as that of the control group. However, increasing the level of sodium lactate to 2.0% reduced further the total psychrotrophic counts. The total psychrotrophic counts for steaks with the addition of 1.5% and 2.0% sodium lactate at day 8 were 8.0 and 7.5 $\log_{10}$ cfu/g, respectively.

Sodium diacetate at 0.1% level significantly ($P<0.05$) reduced the growth of psychrotrophic microflora, and extended the lag phase of the psychrotrophs growth period when compared with control and steaks treated with 1.5% or 2.0% sodium lactate. The total psychrotrophic counts at day 10 for steaks treated with 0.1% sodium diacetate alone reached 5.9 $\log_{10}$ cfu/g. This count was significantly ($P<0.05$) lower than the steaks treated either 1.5% or 2.0% sodium lactate, and the control group, which had counts of 8.8 $\log_{10}$ cfu/g, 8.5 $\log_{10}$ cfu/g, and 9.1 $\log_{10}$ cfu/g, respectively at day 10 of storage. Steaks treated with 0.1% sodium diacetate alone had an extension of lag phase of up to 4 days. Even though sodium diacetate when used alone effectively reduced the total psychrotrophic counts, additional reduction (P<0.05) in total psychrotrophic counts was observed when sodium diacetate was combined with sodium lactate. The data demonstrated that sodium lactate and sodium diacetate when used together resulted in a synergistic effect.

Based on the binding integrity scores, all treatments had scores of 5.0 (maximum binding integrity), except for restructured turkey breasts stored frozen for 1 month and treated with sodium diacetate produced steaks with binding scores of 4.78 and 4.83 on day 6 and 8, respectively. Based on the binding scores for each treatment over time of storage, all the treatments had scores of 4.6 or higher. The only exception occurred for restructured turkey breasts stored frozen for 1 month, and treated with combination of 1.5% sodium lactate and 0.1% sodium diacetate which produced steak with binding score of 4.3 at day 0. Even though restructured turkey steaks when treated with sodium diacetate and/or sodium lactate had significantly (P<0.05) lower binding strength, however, based on the binding integrity and binding scores, the Fibrimex® binding system was able to hold the meat pieces together without falling apart when handled.

Steaks treated with 0.1% sodium diacetate did not differ significantly (P>0.05) in the water activity when compared with untreated steaks (control). However, steaks treated with 0.1% sodium diacetate had significantly ($P<0.05$) higher water activity when compared with steaks treated with either 1.5% or 2.0% sodium lactate. Besides, the treatment groups for steaks with the addition of both sodium lactate and sodium diacetate were found to have lower ($P<0.05$) water activity than the steaks that were treated with only sodium diacetate. Similarly, the treatment groups for steaks treated with only sodium lactate had significantly ($P<0.05$) lower water activity when compared with the control group. Overall, in all the treatments, the water activity were greater than 0.9, thus from practical standpoint, spoilage bacteria would still be able to grow in the product. Therefore, even though statistical significant differences were observed among the treatments for water activity through 8 days storage, the changes in the water activity were very slight and practically insignificant.

In general, steaks with sodium lactate had lower L^* value when compared with control through 8 days storage. Even though the significant differences were not consistent over the month of storage, steaks treated with sodium diacetate had higher L^* values than untreated steaks except for restructured turkey breast kept for 2 months at -30°C which produced steaks with similar L^* value at day 2. In general, steaks with combination of sodium lactate and sodium diacetate had higher L* values when compared with steaks treated with only sodium lactate. Similarly, in general, steaks treated with only sodium diacetate resulted in higher L* values when compared with steaks treated with combination of sodium lactate and sodium diacetate. The a* values for all treatments decreased with increased storage time. However, there was a slight increase in the b* values with increased storage time. No significant differences were observed among the treatment comparisons for a* values except at month 1. Restructured turkey breast treated with sodium diacetate and stored frozen for 1 month, produced steaks that had significantly ($P<0.05$) higher a* value at day 8 when compared with control and steaks treated with 2.0% sodium lactate. In general, at all storage conditions, steaks treated with 0.1% sodium diacetate or combinations of sodium lactate and sodium diacetate had slightly higher a* values than steaks treated with 2.0% sodium lactate.

Even though the distributions of the significant differences were inconsistent with storage time, steaks treated with 0.1% sodium diacetate generally displayed slightly higher b* values compared with untreated steaks, and steaks treated with 1.5% or 2.0% sodium lactate at all storage conditions. As with a* values, the difference in the b* values among treatment comparisons were very small, ranging from 0.5 to 1.1 units. Even though there were some statistical significant differences in the b* values at different storage time for some comparisons, the differences among the treatments at each day were very small and could be considered as practically not significant. Such small differences were detectable by objective method for color measurement, but for the consumers, such differences would most likely goes unnoticed.

At month 1, 2, and 3, steaks treated with either sodium lactate or combinations of sodium lactate and sodium diacetate had lower ($P<0.05$) thaw loss than the control or steaks treated with sodium diacetate. There were no significant differences for cooking yield, fat, moisture, and protein among the treatments. However, steaks with sodium lactate had higher ($P<0.05$) ash content when compared with untreated steaks and steaks treated with sodium diacetate. Even though TBA values for steaks treated with sodium diacetate and/or sodium lactate were higher ($P<0.05$) than control, the TBA values were less than 1 mg malonaldehyde/kg for all treatments for up to 3 months of storage which were below accepted human threshold of 1.00 for detection of rancidity (Tarladgis et al., 1964).

There were no significant differences ($P>0.05$) in juiciness among all treatments. Steaks treated with sodium lactate were not significantly different ($P>0.05$) in flavor intensity than control. Similarly, steaks treated with combination of sodium diacetate and sodium lactate were not significantly different (P>0.05) in flavor intensity than steaks treated with only sodium lactate. Higher percentage of detectable flavor notes associated with sodium lactate were noted by the panelists as the level of sodium lactate increased. The percentage of panelists detecting off-flavor notes for steaks treated with 1.5% and 2.0% sodium lactate were 34.38% and 53.13%, respectively. When the steaks were treated with combination of 0.1% sodium diacetate with either 1.5% or 2.0% sodium lactate, the detectable off-flavor notes were 54.17% and 51.04%, respectively. Untreated steaks and steaks treated with 0.1% sodium diacetate had lower percentage of detectable off-flavor notes, 14.58% and 5.21%, respectively, when compared with steaks treated with sodium lactate or combination of sodium lactate with sodium diacetate. Therefore, future work may be required to determine the potential use of other combination of additives with sodium lactate and sodium diactetate that might help to reduce the off-flavor related to sodium lactate.

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BIOGRAPHICAL SKETCH

Mohamed Shafit Hussain was born on June 10, 1957, in Sabak Bernam, Selangor, West Malaysia. In 1981, he received the degree of Doctor of Veterinary Medicine (D.V.M.) from Universiti Pertanian Malaysia, Malaysia. He was employed by the Malaysian Agricultural Research and Development Institute for nineteen years. In 1990, he received the degree of Master of Science from the Animal Science Department, University of Florida, Gainesville, Florida. In May 2000, he will receive his degree of Doctor of Philosophy from the Animal Science Department, University of Florida. After graduation, he plans to return to Malaysia and resume his work at the Malaysian Agricultural Research and Development Institute.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Sally K. Williams

Sally K. Williams, Chair
Associate Professor of
Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ramon C. Littell
Professor of Statistics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Roger L. West

Roger L. West
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Murat O. Balaban
Professor of Food Science
and Human Nutrition

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James N. Bacus
Associate Professor of
Animal Science

This dissertation was submitted to the Graduate Faculty of the College of Agricultural and Life Sciences, and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May 2000

E. Jane Luzar
Dean, College of
Agricultural and Life
Sciences

Dean, Graduate School